



LaRC 20-Year Center Revitalization Plan

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The final report of the Vibrant Transformation to Advance Langley (ViTAL) Team

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Executive Summary

For nearly 100 years Langley has made significant contributions to the Aeronautics, Space Exploration, and Earth Science missions through research, technology, and engineering core competencies in aerosciences, structures and materials, characterization of Earth and planetary atmospheres, aerospace systems analysis, and more recently, in technologies associated with planetary entry, descent, and landing. An unfortunate but inevitable outcome of this rich history is an aging infrastructure where the longest serving building is close to 80 years old and the average building age is 44 years old. In the current environment, the continued operation and maintenance of this aging and often inefficient infrastructure presents a real challenge to the Center and the Agency in the trade space of sustaining infrastructure versus investing in future capabilities.

For several years now, NASA and LaRC have been encouraged by the Executive (Office of Management and Budget) and Legislative (Congress) Branches of the federal government to reduce infrastructure costs. Most recently, Congress reinforced this position with language in the NASA Authorization Act of 2010 stating that NASA was, "...holding onto facilities and capabilities scaled to another era." Further, the NASA guidance for formulating the FY14 budget specifically states infrastructure reduction goals: 1) continue implementation of Agency Facility Strategy to renew and sustain its capabilities in fewer, more efficient facilities; 2) reduce facility operating costs by 2% in FY14 ranging to 10% by FY18 through cost-effective closure, energy efficient improvements, and other means through the Technical Capabilities Forum (NTC); and 3) discontinue any capability for which the Agency has no projected use during FY14-18 unless the Administrator decides otherwise and unused or excess capabilities where suitable alternatives exist.

To address these issues, LaRC developed and has begun to implement a major 20-year revitalization strategy which includes six new, state-of-the-art facilities, renovation of critical infrastructure, and demolition of non-essential assets all of which enable LaRC to respond to the strategic and infrastructure challenges of the Agency while making the Center more efficient to operate. Execution of this 20-year revitalization strategy will result in over \$100M in maintenance and utility (M&U) savings (over the 20-year period), a deferred maintenance (DM) reduction in excess of \$135M, and the elimination of 1.21M sq. ft. of space with an associated CRV of approximately \$1.1B. The M&U savings can then be applied to critical assets that are currently underfunded. In addition to the proposed new construction, the strategy identifies twelve facilities for various degrees of renovation and repurposing.

The successful implementation of the center 20-year revitalization plan requires funding from multiple sources; but primarily, the annual construction of facilities (CoF) and recapitalization (Recap) appropriations from Congress will be required to support the timely execution of the plan. LaRC has strategically developed a plan that fits within our reasonable expectations of funds from the CoF and Recap programs. Finally, the 20-year revitalization plan has been institutionalized in the center and agency Master Plan.

1.0 Introduction

During 2011-2012, NASA Langley Research Center (LaRC or Langley) developed a strategic plan to revitalize the center infrastructure. The strategic plan is founded on two essential tenets that the center infrastructure will enable the center workforce to execute the future NASA mission **and** place the center on a sustainable path forward. The future work of the center is anchored by the current NASA strategic plan which includes long-term mission goals and objectives and the associated near-term program of record. The goals for a sustainable infrastructure are based on a two-part cost-of-ownership model including: (1) yearly operational costs that do not escalate over time incompatible with a constrained or flat agency budget, and (2) avoids an increasing deferred maintenance burden that could jeopardize mission execution over time. The LaRC 20-year Revitalization Plan includes six new, state-of-the-art facilities, renovation of critical infrastructure, and demolition of non-essential assets all of which enable LaRC to respond to the strategic and infrastructure challenges of the Agency while making the Center more efficient to operate. In addition to the proposed new construction, the strategy identifies twelve facilities for various degrees of renovation and repurposing. The strategy and details of the plan are documented in this report.

1.1 Background

The Langley Research Center (LaRC or Langley) was founded in 1917 by the National Advisory Committee for Aeronautics (NACA) and in 1958 became a field center in the newly formed National Aeronautics and Space Administration (NASA). For nearly a century, LaRC has pioneered research and developed innovative technologies in support of NASA missions in Aeronautics, Space Exploration, and Earth Science. All aircraft developed in the United States have benefitted from the analytical and experimental work done by the researchers and engineers at LaRC utilizing a complete suite of wind tunnels that span the speed regime from subsonic to hypersonic, novel materials and structures, and flight research systems. New instrument systems for measuring and characterizing the Earth's atmosphere were created from breakthroughs in the laboratory and developed into fully-operational, space-based instruments. The ability to work across the complete spectrum from basic research to systems applications gives the center a proven history of developing and integrating technologies into flight systems. However, a significant portion of the infrastructure and buildings necessary to meet future mission and

program milestones are aging, inefficient, and often unreliable; and, at this point, LaRC's longest serving building is nearly 80 years old and the average building age is 44 years old. Currently, approximately 50% of LaRC's buildings are over 50 years old! See Figure 1. This trend in aging infrastructure is not unique to LaRC or NASA, as numerous other government installations across the United States have assets that were constructed in the post-World War II cold war era of the 1950's and 60's. The three key drivers for the LaRC revitalization strategy and implementation plan are (1) readiness to execute future NASA missions, (2) adaptable to evolving mission and programmatic requirements, and (3) accommodating of societal trends and technological improvements.

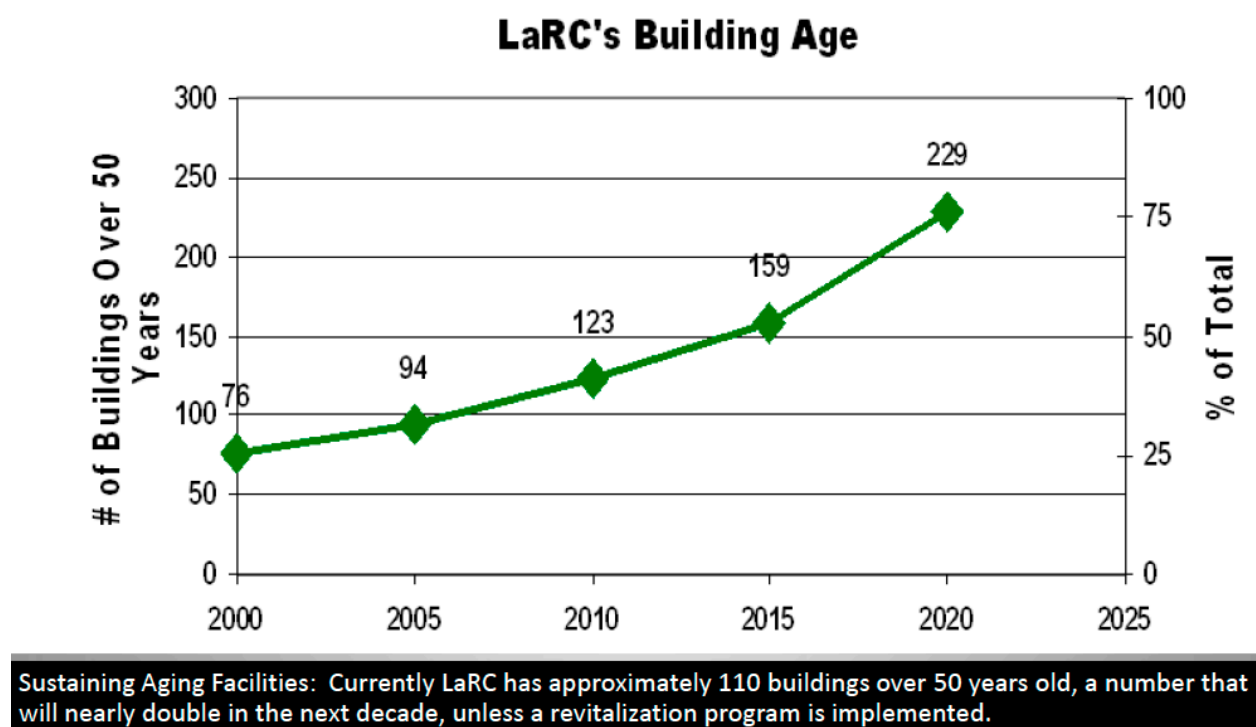


Figure 1, Number of LaRC buildings over 50 years old, as of 2008

For several years now, NASA and LaRC have been encouraged by both the Executive and Legislative branches of the federal government to reduce infrastructure costs. Most recently, Congress reinforced this position with language in the NASA Authorization Act of 2010 stating that NASA was, "...holding onto facilities and capabilities scaled to another era."¹ The aging infrastructure, the push to consolidate, and the continuing budget challenges have created an environment where meeting Agency mission goals and objectives have become more difficult and costly. The National Research Council's Committee on the Assessment of NASA Laboratory Capabilities noted in their 2010 report, "Many researchers expressed the belief that NASA will not be able to maintain its core capabilities let alone to develop them."² Additionally, the Office of the Inspector General recently released a report³ on the NASA infrastructure and facilities stating: "NASA is the ninth largest Federal Government property holder, with real property holdings of more than 100,000 acres and approximately 5,000 buildings and other structures encompassing more than 44 million square feet. NASA's property holdings are located

throughout the world and include commercial office buildings, warehouses, test stands, laboratories, wind tunnels, launch pads, antenna arrays, airfields, roads, and utilities. In total, the assets represent more than \$26.4 billion in current replacement value. However, 80 percent of NASA's facilities are 40 or more years old and many are in need of repair and refurbishment. At the same time, the Agency is undergoing considerable changes in mission focus, with the Space Shuttle Program ending after 39 years. Accordingly, NASA will have to make some difficult decisions to evolve toward the most efficient facility structure for its future. The Agency's aging infrastructure has been identified by NASA, the Office of Inspector General (OIG), the Government Accountability Office (GAO), and Congress as a top challenge for the Agency for nearly a decade. In the NASA Authorization Act of 2010, ***Congress directed the Agency to complete an Institutional Requirements Study examining its assets and identifying a strategy for moving forward.***"

In response to growing concerns, LaRC leadership decided to expedite previous plans to address aging infrastructure through a repair-by-replacement program called New Town and extended the plan to include all major center assets. The result of this action is a comprehensive 20-Year Center Revitalization Plan. The overarching goal of this plan is to sustain or enhance the Center's core capabilities through repair-by-replacement or rehabilitating existing buildings based on a credible business case. The goals included reducing the footprint of the Center, incorporating a healthy, pedestrian-friendly environment similar to a college campus, and transforming the remaining infrastructure to be energy efficient, sustainable, and adaptable to changing mission and societal needs. These goals are fundamental to ensuring that Langley remains a critical research and development Center for the NASA and the Nation well into the 21st Century. Langley's value to the Nation is the repository of highly specialized knowledge (core competencies) and the ability to develop mission-enabling technology provided through the breadth and depth of our core competencies in: aerosciences [flight sciences]; structures and materials; systems analysis; characterization of [planetary] atmospheres; and entry, descent, and landing; coupled with systems engineering to provide multi-disciplinary integrated solutions. These core competencies are used as a focal point to answer the grand challenges underlying NASA's missions in Aeronautics, Human Exploration and Operations, Science, and Space Technology. Langley maintains a diversified portfolio across these primary NASA missions by successfully leveraging our multidisciplinary capabilities to maximize leadership and contributions to the Agency missions, Figure 2. Coupled with the Langley core competencies is the Center's ability to collaborate with external partners in industry, universities, and other Government agencies. These partnerships enhance our mission output and continually create and incubate new ideas and concepts. They can supplement Agency programs and projects, drive innovations and develop advanced technologies. The Center infrastructure is central to this value proposition, and the revitalization of the infrastructure is critical to sustaining and growing Langley's portfolio.



Figure 2. Future NASA Missions: *extend and sustain human activity across the solar system, expand scientific understanding of the earth and the universe in which we live, and advance aeronautics research for societal benefit*

Langley's revitalization strategy embraces our heritage while enhancing prospects for future missions. Being mindful of expected societal changes, establishing a healthy and stimulating work environment, and providing suitable and effective tools will be keys to attracting brilliant young professionals to support the Langley of 2050. Future NASA missions, as illustrated notionally in Figure 2, will be achieved by advances in collaborative computational modeling and technology development across each Langley core competency. Improvements in information technology, with extreme connectivity, will enable Langley to work with a far greater number of external and international partners. Virtual presence and improvements in modeling techniques and information processing will combine with a greater societal ability to leverage research and engineering tools for accelerated worldwide technology development.

Meeting these challenges and continuing to remain a preeminent research and development center through the year 2050 and beyond will require building advanced, flexible, and sustainable research and development facilities. These facilities will require state-of-the-art equipment and an interconnected information technology infrastructure to execute the future NASA mission and to attract, retain, and promote the brightest minds necessary to create the future.

1.2 Thoughts about the future work environment

The world is changing in many profound ways that will affect both the future mission of NASA LaRC and the way people will work in the future. It has been clear for some time now that the information technology revolution and the less mature nanotechnology and biotechnology revolutions are having profound societal implications. These revolutions, sometimes thought of as mega-trends, all have common elements centered around advanced computational modeling of small scale physics. Whether it is nanotechnology, biotechnology, information technology with the associated computational technology, all of these megatrends are converging on science at the very small scale where it is profoundly important to consider the quantum effects at play with physics at that scale. In contrast to these trends, much of the classical engineering standard practices are based on Newtonian physics and the first principles are modeled using concepts of continuum mechanics. We expect over the next several decades that our current incomplete physics-based continuum models and the growing modeling and simulation capability will continue to mature and eventually be rendered to the engineering standard practices. These two off-setting trends, perhaps best thought of as the maturation of the current technology development “s-curve” and the advent of a new s-curve, will greatly affect the long-term nature of the work LaRC will be conducting and the facilities, laboratories, and computational infrastructure (tools) that will be essential to executing this future NASA mission.

Rapid technology advances are happening all around us today. Whether we look back over a few years or many decades, we find evidence of the accelerating pace of technology development. NASA must not stand by and watch these changes, but rather, NASA needs to proactively embrace the new scientific and technology trends. There are six developments that are undeniably changing the nature of the work we do and essence of how we do this work. These are described below.

Advances in Computer capability and Computational Modeling and Simulation

Just 25 years ago in the late 1980's, IBM PCs were becoming common, and the Macintosh was just introduced, which included an 8 MHZ 16-bit Processor and a 40MByte Hard Drive. During this time frame, a 32-bit MicroVAX was all the rage in laboratory computing. Now, the current version of a Macintosh is 20,000 times faster, with 10,000 times the storage capacity. Progress in computer capability over the past 50 years is characterized by Moore's Law which observed that computer capability is doubling every 18 months. This trend is not yet fully exhausted; and in the not too distant future, we may also harness the promise of cloud computing, quantum computing, and advanced machine intelligence. We are simultaneously experiencing a rapid maturation of our physics-based design tools and the affordable and ever-faster computing capacity for the application of those tools to complex problems. These tools include, but are not limited to, flow physics, flight dynamics, celestial mechanics, structures and materials, thermodynamics, electromagnetic, and airspace system infrastructure. Most physics-based engineering tools are based on the principles of classical (Newtonian) physics and loosely the general theory of relativity, but not on quantum theory. These engineering tools are rapidly maturing and the leading edge of research is now quantum mechanics, multi-scale and multi-physics modeling, and higher order methods for advanced numerical methods and algorithm development. In the not too distant future, integrated, system-level, multidisciplinary modeling and simulation (ModSim) capability will allow full flight simulation and may eventually replace the current test-based flight system

design/development standard practice. The 21st Century Laboratory will be an environment, both physically and virtually, where these tools are advanced, integrated, validated, and applied to problems of significance to the Agency.

Advances in Materials Science

Recent advances in materials science, specifically advances in nanotechnology, hold the promise of changing everything we know and do with respect to composition, design, and manufacturing of materials. These materials, already under development, have the promise of increasing strength-to-weight ratios an order of magnitude or greater than current steel and aluminum alloys in common use today and exhibit orders of magnitude increase in electrical and thermal conductivity when compared to conventional metallic materials. And perhaps more importantly, these materials can be designed to optimize unique combinations of multifunctional properties thus leading to the development of innovative new products. As this technology is just beginning to blossom, materials design at the quantum/atomic level (materials genomics) and revolutionary additive manufacturing methods (molecular manufacturing and 3-D printing) are identified as a national grand challenge.

Advances in Automation

With the synergistic integration of advancement in computational capability, material sciences, and biological sciences, the rapidly advancing field of automation will profoundly affect the nature of our future mission and the way we will be executing it. For example, the future vision of autonomous vehicles enabling human transportation is no longer the domain of the science fiction writers. Likewise, our ability to conduct expansive robotic space science missions is improving with every generation of autonomous and interactive technologies. In other domains, automation is affecting many traditional jobs in industrial manufacturing and the distribution of goods and services resulting in increased productivity and reduced operational costs. These trends will continue as wireless communications improve, computers continue to increase in capability, and automated systems decrease in size and energy requirements. Imagine a center where the physical infrastructure could be accessed remotely from any geographic location and our scientist and engineers could interact as if they were co-located at the site of the facility in use. Such capability now exists in many specialized fields and will replace our industrial-age ground test facilities and research laboratories.

Changes in World Demographics

There are undeniable changes in world demographics that are having a profound influence on our world, as in the advances made in China and India. India has about 1/6th of the world's population, while it has only 2.4 percent of the world's land area. China is the world's largest population, with about 1.34 billion people according to the 2010 census. It is profoundly clear that the burgeoning middle classes of these two countries are beginning to represent a significant change in the global economy. Both India and China have a growing middle class population that will far exceed the US, with even a small fraction of their populations achieving 'middle class' status. While the United States graduates 70,000 engineers, India graduates 450,000 and China graduates 700,000 engineers. It is clear that such trends in global demographics will continue to progress as more and more 'under-developed' countries successfully enter the global marketplace.

Changes in the consumption of energy

With the emergence of the global concern for the environment, green efforts will continue to grow. With growing concerns over the environment and climate change, what will this mean for NASA's laboratories? NASA has already made contributions to our understanding of global greenhouse gas emissions, global pollution, water supply purity and global agricultural activity. Our research and space-based science instruments are beginning to generate the data describing the earth's radiation budget and the effects of clouds and aerosols on our environment. Questions about how the worldwide growing dependence on energy from fossil fuels will affect our climate and our standard of living must be a consideration in any long-term strategic plan for the agency mission as well as the revitalization of the center infrastructure.

Innovations in Innovating

We are also experiencing significant innovation of the innovation process itself, leading to much shorter times between the development of new technologies and their appearance in engineered solutions. The 21st Century innovation process requires a new model for the relationship between the research and technology development process and the innovation process. The 21st Century Laboratory must be adept at cultivating such new relationships with innovators in order to remain relevant and viable. This change, as with all of these changes, is closely interwoven with the great increase in communication courtesy of the internet. In addition, the accelerating advances in science are being fuelled by the massive increase in information that is readily available to anyone, as well as the intense interactive communications among collaborators.

One of the most profound implications of the information technology revolution is the impact on society. The growing use of technology-enabled social networks is beginning to change how people interact and these changes are beginning to impact the work environment. How will these societal changes influence how work will be defined, organized, and executed in the future? Not only are people in many professions beginning to telework occasionally, entire corporations are being reinvented without traditional bricks-and-mortar office infrastructure and teleworking is a requirement for employment. Further, there are many examples of highly networked organizations conducting work on a 24/7 basis using a worldwide, geographically dispersed workforce.

Terms like teleworking, telecommuting, hoteling, and hot-desking are all used to refer to work done outside of the traditional on-site work environment. Alternate work strategies are important to meeting future mission requirements, attracting the next generation of workforce, and reducing infrastructure costs. Although small now, the percentage of federal employees taking advantage of alternative work arrangements is rising. Surprisingly, 61% of federal employees are considered eligible for telecommuting, and only 5.2% do on a regular basis. Federal budget pressures and government mandates for the federal workforce, including the Telecommute Act⁴, emphasize sustainability, continuity of operations, shrinking technology replacement cycles, and cloud computing as primary drivers of change.

According to several surveys, benefits to the employer include an average 27% increase in productivity on telecommuting days due to fewer interruptions and wasted time in meetings. Adapting alternative work arrangements will also allow Langley to broaden the geographic talent pool. Flexible work hours enable a better work life balance, improved morale, and added job satisfaction. Behaviors and best practices developed through telecommuting will help Langley engage in additional worldwide collaboration in research and engineering. Advantages for employees include a greater ability to concentrate, more time to spend with family due to reduced travel times and less auto maintenance and fuel costs. For example, the average commute to Langley is 14.3 miles each way. Assuming an individual telecommutes two days per week, the average savings for fuel cost amounts to approximately \$500 per year.

Looking forward, workforce and workplace flexibility will be an important component of Langley's strategy. The megatrends briefly discussed above have the potential to greatly affect how we conduct the NASA mission in the future. Indeed, these trends when extrapolated well into the future raise profound questions of what is the definition of a field center and will we need a dedicated co-located workforce on-site, as is our current organizational/operational model. While much of this speculation will perhaps become the rubric for defining the future center after the next center, we expect to experience continued emphasis on operational cost containment, reducing the footprint, reducing resource consumption, and recognizing the needs of the emerging next generation tech-savvy labor force, with some elements of the workforce contributing to our mission from geographically dispersed locations. These expectations give rise to guiding principles that shaped the center 20-year revitalization plan.

1.3 Agency infrastructure revitalization strategic goals and objectives

To address the growing concern over the state of the infrastructure, NASA recently published an Agency Master Plan that was submitted to Congress in March 2012⁵. This plan provides guidance to NASA field centers for reducing the cost of ownership of its infrastructure and reducing the associated yearly operational costs. These goals and objectives are specific for Current Replacement Value (CRV) and energy and water consumption. The guideline for CRV implies a change to the center's foot print. For Langley's CRV, the goal is to reduce from the 2008 baseline of \$3.3B, and the objectives are to reduce 10% by 2020 and 15% by 2055 (by the Agency's "Slow and Steady" recapitalization model). In addition, the agency has set a "mission readiness" goal, defined as assets less than 40 years old, of 62% under 40 years by 2055. (Recall that 80% of the current agency assets exceeds their 40 year design life.) For energy consumption, the goal is to reduce from the 2003 baseline of 126,000 British Thermal Units per Gross Square Feet (BTU/GSF) by 30% in 2015 in Goal Subject Buildings.⁶ For water consumption, the goal is to reduce from the 2007 baseline of 46 gallons/GSF by 16% by 2015.⁷ Perhaps the hardest specific Agency objective for Langley to address is to increase the utilization of Renewable Source Energy to 7.5% by 2015.⁸ Langley will attempt to meet this objective through the continued purchase of renewable energy credits, by operating a photovoltaic field to supply energy to meet the needs of the Langley Badge and Pass Office, and by implementing renewable energy systems into the New Town buildings such as geothermal wells and photovoltaic fields. Finally, the agency has not assigned a specific goal for reducing deferred maintenance (DM). However, Langley's DM has risen from about \$150M to about \$280M in the past decade. With the recent building demolitions, the DM has reduced to just under \$250M

but will continue to rise unless decisive actions are taken regarding our remaining infrastructure. The goal of the 20-Year Revitalization Plan is a sustainable infrastructure, meaning the DM remains level over time as new assets replace old assets and aging buildings are demolished.

The implied goal to reduce foot print is coupled with the reduction in CRV. Although there is not a specific objective, Langley has demolished 400,000 GSF since 2005 and is on track to reduce by 1,065,000 GSF through 2023. This amount is more than 25% of the approximately 3,700,000 GSF Langley had in 2005. More recently, the HQ guidance to field centers, expressed in the form of expectations, is that the repair-by-replacement model should accommodate a 2 square foot reduction in foot print for every 1 square foot of new building space. ***So the CRV reduction goal, the utility consumption reduction goals, and the two-for-one expectation for new infrastructure form the basis of the goals and objectives to be achieved by the LaRC 20-Year Revitalization Plan.*** The explicit benefit of reducing consumption and foot print is a decrease to the operations and maintenance cost burden the infrastructure places on the Center. The implicit benefit of these reductions will be a greater likelihood the Center will be able to invest in the new technical capability and skills required for the future.

The details of the center plan for infrastructure stewardship, both near-term and long-term, are documented in the Center Master Facility Plan. The Center Master Facility Plan provides a comprehensive presentation of how assets relate to the technical mission, provides for the sustainable development of the Center and its facilities and infrastructure, and integrates with and supports the Center's planning and budgeting processes. Oversight for the Center Master Facility Plan is provided by the Center Director and NASA HQ. The Center Master Facility Plan reflects and implements the Agency's strategic infrastructure objectives to sustain the ability to meet current and future mission requirements; accommodate technical capabilities in fewer, more efficient and cost-effective facilities; implement the "slow and steady" recapitalization model and reduced CRV. Implicit to the recapitalization model is a requirement to reduce facility inventory without any reduction in technical capability. The Center Master Facility Plan also focuses on the overall reliability of the facilities and the ever-increasing operational and maintenance costs required to sustain an acceptable level of readiness.

1.4 Strategic Approach to developing the Center revitalization plan

To enable the development of a comprehensive, integrated, center revitalization plan, LaRC first enlisted the help of subject matter experts from all core competencies within the center to develop a comprehensive future technical vision of the likely work to be executed by LaRC as part of the agency mission. With this long-term technical vision as a guide, these teams of discipline experts identified the critical workforce skills and physical infrastructure deemed to be essential to execute the future agency mission. A centerwide team, named ViTAL (Vibrant Transformation to Advance Langley), was then commissioned to integrate the finding of these discipline teams into a long-term center revitalization plan according to the infrastructure guidance provided from the agency, Section 1.3 above. The resulting comprehensive 20-Year Center revitalization plan was incorporated into the official Center Master Facility Plan, thus institutionalizing the long-term center physical infrastructure strategy. It is expected that the Center Master Facility Plan will be updated periodically as details of the revitalization plan change to adapt to significant future developments.

The center's future technical vision is anchored by the current NASA Strategic Plan⁹ and several additional national strategic documents such as the Office of Chief Technologist's Technology Road Maps¹⁰, Earth and Planetary Science Decadal Surveys¹¹, and the National Aeronautics Research and Development Policy and Plan¹². Using these documents and other sources of information, the discipline teams developed strategic plans for the next 20+ years. The reference documents provide general goals and objectives about the long-term mission of the agency. However, beyond the next 10 years, the visioning work becomes quite speculative. The teams were pushed to think both about evolutionary progress within their disciplines and to also consider the possibility of "orthogonal" breakthroughs in science and technology that could result in profound changes to how we will conceive and execute the future agency mission. This technical vision of the future provides an answer to the question, "what will we be doing in the future to execute the NASA mission?" Providing a reasonable answer to this fundamental question of "what will we be doing" is essential guidance for strategic planning and necessary to then address the associated question of "how will we do it". Once the technical vision of the future was established as the baseline, new teams with specialized experimental domain knowledge were then charged with defining the infrastructure tools needed to execute the work, including major ground test facilities, research laboratories, computational infrastructure, and the supporting horizontal (utilities) infrastructure. In order to push these teams beyond their traditional view of the center, the teams were required to answer the following questions about their specified infrastructure requirements:

1. What is the comprehensive story that answers the following "why" questions?
 - Why do we need this capability, ie., why is it essential? What outcomes will this experimental capability enable?
 - Why should we advocate for new capability, what gap in current capability does it address?
 - Why should we close an existing capability or combine existing facility/labs?
2. If we do not have all the essential experimental capability at the center, could we partner with other NASA centers, other governmental organizations, industry, or academia and use their existing facilities?
3. If we divest of an existing facility/laboratory, does it diminish the center's integrated end-to-end research, technology, and engineering development capability?

Several of the more significant overarching findings from these future visioning studies are: (1) Langley's unique value proposition is built on its 5 core competencies which form an integrated, end-to-end research and engineering capability that spans across the complete TRL scale from concept-to-flight, and from ideation-to-mission management. This integrated capability is strategically important to NASA as it will enable the development and application of innovative technologies to meet the unique requirements of the one-of-a-kind engineering and mission projects executed by the agency. (2) Experimental facilities and laboratories will remain an essential element of the core capability required to conduct leading edge research and to develop system level technology to enable NASA's future missions. (3) Large-scale ground test facilities will continue to be required at least in the near-term for integrated flight systems design/development, processing and qualification. (4) Greater investments in computational infrastructure and improvements in first-principles modeling and simulation techniques will

allow Langley to significantly reduce the amount of testing required for flight system development in the long-term. And (5), the potential for increased virtual presence will allow for a greater level of remote testing and international collaboration. These five key findings formed the overarching principles that guided the development of the 20-Year Center Revitalization plan. Beginning with Chapter two the complete details of the revitalization plan will be described along with the decision-making process that was employed to identify future facility and laboratory requirements and to disposition every current physical asset in the center inventory. **Please note that Appendix A contains a description of each Langley facility or laboratory cross-referenced to the building number.**

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2.0 Development of an Integrated Facility and Laboratory Strategy: A Framework for Decision-Making about the future Center infrastructure

2.1 Introduction

At the outset of the development of the center revitalization plan, it was recognized that LaRC needed an integrated strategy that provided a coherent framework for future decision-making. To be comprehensive, the strategy needs to address the future requirements and disposition of all current facilities, laboratories, and office buildings on center; capture the requirements for the new capabilities required to execute the future agency mission; and integrate this capability with the supporting infrastructure which includes water, electrical, and steam utilities, special capability such as the compressor station that provide high pressure air to most center wind tunnels, and the compute infrastructure which underpins all current center activities and is trending to ever increasing importance going forward. And as discussed in the introductory section 1.4, the integrated strategy must be anchored by the future technical vision of what and how LaRC will execute the future agency mission. To achieve the integrated strategy, the ViTAL team synthesized the findings of the 11 internal future facilities study teams and the multiple relevant external national studies. (See section 1.4.) Each asset is directly linked to critical future needs and mission relevance. The resulting integrated facility and laboratory strategy is viewed to be very robust because it systematically identifies the various options available to execute the future agency mission and provides a decision-making framework to guide the future disposition of all the center assets. Taken together, the strategy provides a comprehensive approach to guide the long-term stewardship of the center's physical infrastructure. This chapter provides an overview of the strategy and the figures of merit (FOMs) used by the ViTAL team to determine the final elements in the 20-Year center revitalization plan. (Complete details of the integrated strategy may be found in Appendix A.)

2.2 LaRC infrastructure asset groupings

The LaRC infrastructure inventory is quite extensive with many dedicated ground test facilities and research laboratories. Adopting the agency assignment of center core

competencies, LaRC has dedicated research laboratories, and specialized small-scale and large-scale ground test facilities in **aerosciences**, **structures and materials**, and **characterization of [earth and planetary] atmospheres**. The center also has extensive physical assets in **systems engineering**; and these four competencies/capabilities provide the cross-cutting capabilities that are enabling to our core competency in **entry, descent, and landing (EDL)**. The center core competency in **systems analysis** is predominantly a computational-intense enterprise, but does require test data to support and verify advanced code development, especially flight data. The integrated strategy is organized into the following 17 disciplinary asset groupings, with the first 14 being primary and the latter 3 being cross-cutting support disciplines that underpin the capabilities in the 14 primary asset groups. The LaRC infrastructure asset groupings are as follows, with the core competency identified in the bracket:

1. Aerodynamics (subsonic, transonic, supersonic) [[aerosciences and EDL](#)]
2. Acoustics [[aerosciences](#)]
3. Aerothermodynamics (entry, descent, and landing) [[aerosciences and EDL](#)]
4. Hypersonic Airbreathing Propulsion [[aerosciences](#)]
5. Materials and Structures (includes nondestructive evaluation sciences, COLTS, and LandIR [[structures and materials and EDL](#)])
6. Electromagnetics and Software-Intensive Flight Systems Laboratories [[aerosciences](#)]
7. Systems Development (Fabrication, Engineering and Environmental Testing) [[cross-cutting](#)]
8. Sensor Systems (Laser/Lidar and remote sensing) [[characterization of atmospheres](#)]
9. Entry, Descent, and Landing (cross-referenced to aerodynamics, aerothermodynamics, materials & structures, & systems development)
10. Langley Aircraft [[characterization of atmospheres, aerosciences](#)]
11. Flight Simulators [[aerosciences](#)]
12. Flight Dynamics & Controls Laboratories [[aerosciences](#)]
13. Crew Systems & Aviation Operations Laboratories [[aerosciences](#)]
14. Science Laboratories and Atmospheric Science Data Center [[characterization of atmospheres](#)]
15. Measurement Sciences (flow physics, acoustics, and combustion) [[aerosciences](#)]
16. Compute Infrastructure (Computer hardware, networks, software & codes) [[cross-cutting](#)]
17. Compressor Station [[aerosciences](#)]

2.3 Langley Values and revitalization planning Figures of Merit:

As the ViTAL team undertook its work of synthesis and final decision-making to construct the 20-Year Revitalization Plan, certain values surfaced as critical factors that influenced the future vision of how the center will execute its NASA mission. These values include:

1. Deep subject matter expertise and broad systems level knowledge are extremely difficult to reconstitute. And furthermore, hands-on experience in conducting experiments and tests is an essential element in developing deep subject matter expertise in virtually every Langley discipline.
2. The Langley tradition is to gain formative experience from conducting small, flexible, easy to operate laboratory scale experiments and tests; then applying these skills to plan

and execute complex, special-purpose tests in large ground test facilities and design development of integrated flight systems. This same process for core competency stewardship can be applied to a hybrid test capability comprised of Langley in-house and external partner facilities.

3. While some Langley laboratories, ground test facilities and experimental aircraft have unique capability much of Langley's capabilities may be found in the combination of facilities resident at other NASA centers, other federal agencies, and U. S. industry and academia. Langley has a rich history of partnering with other organizations to fulfill its mission.
4. If Langley chooses to rely on test facilities owned and operated by non-NASA organizations, the successful execution of the agency mission can only be assured if Langley retains a minimum essential experimental / test capability to preserve the expertise of its current workforce and to train the next generation workforce.
5. Langley must retain the research, engineering and testing expertise to successfully conduct experimental research and support development activities at Langley or at partner organizations.
6. As single discipline physics-based computational codes and multidisciplinary design tools become more mature and computer hardware/software capability continues to expand as expected, the engineering standard practice will become increasingly dependent on computational design and analysis capability and decreasingly dependent on ground test facilities to support engineering design/development/certification requirements.

The ViTAL team adopted the following figures of merit (FOMs) to guide the final decision-making as the comprehensive plan emerged in its final form. The FOMs include:

1. Relevance to the NASA Mission
 - Supports Multiple NASA Mission Directorates (current and future)
 - Ability to Sustain/Develop Core Competency
2. Utilization
 - Usage rates
 - Enables our competitiveness/Reimbursable opportunities
3. Cost of Ownership
 - Maintenance and Utility Costs
 - Deferred Maintenance / Facility Condition Assessment (FCA)
4. Linkage to Center Master Facility Plan (including original New Town concept)
 - Central to Core Campus
 - Sustainability / Energy Efficiency

All options and final elements in the revitalization plan were evaluated against these FOMs. While the team employed a rigorous decision-making tool that quantitatively weighted the FOMs and assigned numerical values to each option under evaluation, perhaps the greatest value in using the FOMs was that it prompted the right discussions and facilitated a consistent and rigorous decision-making process during the team deliberations and then provided an effective communications tool in explaining the team's decisions to our stakeholders.

2.4 Some useful definitions and differentiators

As LaRC is a multi-mission center, the disposition of each unique center asset must be evaluated against all the possible mission-enabling functions that the asset performs. The ViTAL team found it necessary to develop a set of working definitions to guide the evaluation of the infrastructure assets. However, simple definitions do not always communicate the full differentiation between functions and missions. So the team found it necessary to establish the difference between experimental research and engineering development testing.

2.4.1 Working Definitions

NASA Science: development of knowledge, models, and data that explains observable physical phenomena of interest to the NASA mission

NASA Research: creation of intellectual property, data, methods, and models that describe the physical behavior of human endeavors in the earth and space environment necessary to achieve the NASA mission

NASA Technology Development: the achievement of technologies that provide specific systems-level solutions to problems and barriers to achieving the NASA mission

Engineering Design/Development: unique, one-of-a-kind design, development, and fielding of instruments and vehicles to achieve specific NASA (or industry) mission objectives

Production Testing: tests conducted by industry (or NASA) to obtain specific data necessary to support product development, certification, marketing, and operations

Experiments: physical exploration of phenomena not well understood and characterized to support the development of physics-based data, models, and methods for engineering design/development/operations [*why things behave as they do*]

Tests: development of data that describes the physical behavior of system-level concepts, configurations, technologies, and engineered products [*performance data*]

2.4.2 Experimental Research versus Engineering Development Testing

Research experimentation is profoundly different from engineering development testing. Engineering tests are typically designed to provide the “what” answers that describe the performance of a test article, whereas research is about understanding “why” something performs the way it does, i.e., understanding physical phenomena. Research experimentation is often motivated by discovery during the exploration of new ideas and concepts, whereas engineering development tests set the parameters for design and performance. The difference between experimentation and development testing can lead to fundamentally different test objectives and measurement requirements. To illustrate the distinction, consider the wind tunnel testing enterprise. In designing a vehicle, the designer needs to know the “on-body” model's lift and drag to establish the vehicle performance, force and moments for stability and control, and pressure distributions for structural analysis. On the other hand, the researcher conducting flow physics research needs to know about the fluid behavior, primarily full field velocity

components, but may not care about the on-body values of the model. The objective of the research is to develop physics-based computational methods (CFD codes) that can be used to simulate the actual flight conditions and predict the vehicle response. In research, the role of the model is to perturb the flow field so that fundamental fluid flow phenomena can be isolated, studied, and measured.

This fundamental difference between research experiments and development tests also requires wind tunnels to be operated quite differently. The development test requirements are precisely defined, easy to achieve, and the selection of the appropriate tunnel for the test is based on the flight condition to be simulated. The objective of the test is to acquire the test article (model) performance data at specific test conditions (angle of attack, mach number, Reynolds number). Contrast this to research where the test requirements are not precisely known and the research conditions to be achieved can be elusive and may require extensive dwell times to understand phenomena and adjust measurement objectives accordingly. So the emphasis in research must be on tunnel access and operational flexibility. In development tests, the primary differentiator among similar tunnels is test costs. If Langley cannot compete on the basis of test costs, then it will be difficult to sustain our large tunnels on the reimbursable funds from product-specific production tests. Likewise, sustaining our essential capability to perform experimental research will be problematic if we do not have access to the necessary tunnels and will inevitably result in a shift in the research to the smaller less expensive tunnels to operate, even though some loss of research capability will result.

However, the distinction between research experiments and development tests is not sufficiently adequate to establish the need for large-scale versus small-scale ground test facilities. In addressing many important attributes of physical phenomena in both research and engineering development, it must be understood that scale matters. In flow physics, for example, Reynolds number scaling to flight conditions is critical; and Reynolds number depends on the characteristic length scales of the test model and vehicle. If the tunnel conditions do not match flight conditions, important phenomena can be missed. So there will continue to be a need for large-scale wind tunnels as long as CFD codes cannot be relied on for accurate predictions of the full flight envelope. Likewise, a similar scale distinction is present in structures and materials. Consider, for example, damage initiation and growth and failure modes. While materials level coupon tests can accurately duplicate some of the stress states that are critical to the design of built-up structure, geometry and size-dependent instability phenomena such as shell buckling, and complex interactions among structural elements cannot be simulated in materials-level coupon tests. The current structural design practice is the building-block test-based development process. And until our computational codes are fully mature to predict accurately structural failure, we will continue to require large-scale load frames for both research and development testing. Finally, until we succeed in developing comprehensive, multidisciplinary Modeling and Simulation capability that allows for actual flight simulation, a similar argument can be made for the continuing need for research aircraft and flight testing.

2.5 Mission Relevance

Mission relevance is more than just one of several figures of merit, see section 2.3, used to evaluate each asset. It is indeed the paramount consideration because it is the reason the assets exist in the first place. So each future facility study team, and the ViTAL team in its integration function, placed considerable emphasis on how each asset will enable the future mission of the agency. The table shown in Figure 3 was assembled to illustrate the direct mapping of each asset to 5 of the strategic goals in the NASA Strategic Plan.

AGENCY GOALS			
Strategic Goal 1: Extend and sustain human activities across the solar system	Strategic Goal 3: Create the innovative new space technologies for our exploration, science, and economic future	Strategic Goal 2: Expand scientific understanding of the Earth and the universe in which we live	Strategic Goal 4: Advance aeronautics research for societal benefit
HUMAN EXPLORATION & OPERATIONS AND SPACE TECHNOLOGY	SCIENCE	AERONAUTICS	
LANGLEY PROGRAM AND INSTITUTIONAL CAPABILITIES			
<ul style="list-style-type: none">• Entry, Descent, and Landing Systems• Radiation Protection• Structures & Materials for Exploration Vehicles• Aerospace Flight Vehicles Development• Erectable/Deployable Structures• Aerospace System Concept Development & Technology Assessment• Highly Reliable Autonomous Vehicle System• Mission & System Design & Analysis• Human Robotic Exploration Science	<ul style="list-style-type: none">• Earth Radiation Energy Balance• Atmospheric Composition• Active Remote Sensing Instr.• Air Quality• Entry, Descent, & Landing• Space Weather• Planetary Science	<ul style="list-style-type: none">• Civil Transport R&T• Supersonic Aircraft R&T• Hypersonic Vehicles R&T• UAS R&T-unpiloted systems• GA/Regional/PAV R&T• Advanced Vehicle Concepts• Advanced Transportation Sys. Arch.• Technology Assessment and Integration• Computational Tools - Analysis & Design Testing	
LANGLEY FACILITY AND LABORATORY ASSETS			
<ul style="list-style-type: none">1 - Aerodynamics (sub, trans, super)3 - Aerothermodynamics5 - Materials and Structures6 - EM & Software Intensive Flight Sys Labs7 - System Development8 - Sensor Systems (Laser/Lidar)9 - Entry, Descent, & Landing11 - Flight Simulators12 - Flight Dynamics & Controls Labs16 - Computational Simulation	<ul style="list-style-type: none">3 - Aerothermodynamics5 - Materials and Structures7 - Systems Development8 - Sensor Systems (Laser/Lidar)9 - Entry, Descent, & Landing10 - Langley Aircraft12 - Flight Dynamics & Controls14 - Sci. Labs & Atmos. Data Ctr16 - Computational Simulation	<ul style="list-style-type: none">1 - Aerodynamics (sub, trans, super)2 - Acoustics3 - Aerothermodynamics4 - Hypersonic Air-Breathing Propulsion5 - Materials and Structures6 - EM & Software Intensive Flt Sys Labs9 - Entry, Descent, & Landing11 - Flight Simulators12 - Flight Dynamics & Controls Labs13 - Crew Systems & Aviation Ops. Labs16 - Computational Simulation	
Strategic Goal 5: Enable program and institutional capabilities to conduct NASA's aeronautic and space activities			

Figure 3 Mapping of the LaRC facility and laboratory assets to the agency missions and Strategic Goals in the NASA Strategic Plan

2.5.1 Near-term Mission Relevance (the next 5-10 years)

The NASA strategic plan provides long-term goals and objectives; and in addition, the strategic goals and the current program of record are typically a 10-year vision with a 5 year execution plan. A further more detailed level of mapping is provided below for the aerodynamics asset group as an illustrative example. The blue font highlights the current agency programs and projects being enabled by the aerodynamics core capability.

Strategic Goal 1: Extend and sustain human activities across the solar system.

1.2 Develop competitive opportunities for the commercial community to provide best value products and services to low Earth orbit and beyond.

Commercial Spaceflight Programs

- **Commercial Cargo**
- **Commercial Crew**

1.3 Develop an integrated architecture and capabilities for safe crewed and cargo missions beyond low Earth orbit.

Exploration System Development Programs

- **Multi-Purpose Crew Vehicle**
- **Orion Emergency Rescue Vehicle**
- **Space Launch System**

Strategic Goal 3: Create the innovative new space technologies for our exploration, science, and economic future.

3.1 Sponsor early-stage innovation in space technologies in order to improve the future capabilities of NASA, other government agencies, and the aerospace industry.

3.2 Infuse game-changing and crosscutting technologies throughout the Nation's space enterprise to transform the Nation's space mission capabilities.

3.3 Develop and demonstrate the critical technologies that will make NASA's exploration, science, and discovery missions more affordable and more capable.

3.4 Facilitate the transfer of NASA technology and engage in partnerships with other government agencies, industry, and international entities to generate U.S. commercial activity and other public benefits.

NASA Space Technology Roadmaps:

- **TA01. Launch Propulsion Systems**
- **TA09. Entry, Descent, and Landing Systems**
- **TA11. Modeling, Simulation, Information Technology, and Processing**

Strategic Goal 4: Advance aeronautics research for societal benefit.

4.1 Develop innovative solutions and advanced technologies through a balanced research portfolio to improve current and future air transportation.

Fundamental Aeronautics Program

- **Fixed Wing Project**
- **Rotary Wing Project**
- **High Speed Project**
- **Aeronautics Sciences Project**

Aviation Safety Program

- **System-Wide Safety and Assurance Technologies**
- **Vehicle Systems Safety Technology**
- **Atmospheric Environment Safety Technologies**

Aeronautics Test Program

4.2 Conduct systems-level research on innovative and promising aeronautics concepts and technologies to demonstrate integrated capabilities and benefits in a relevant flight and/or ground environment.

Integrated Systems Research Program

- **Environmentally Responsible Aviation**

Since many assets are enabling to several agency goals, Figure 4, each asset may be listed several times. But it should be clear that the function an asset may fulfill in meeting one goal may be different than how the asset is used to enable another goal. For example, the role of wind tunnels (aerodynamics asset group) in conducting aeronautics research is quite different than how we must use the data from wind tunnels to fulfill the goals of exploration such as developing the Space Launch System aerodynamics design database. This is one reason why multiple tunnels comprise the asset grouping. In research, small scale unit problems can be conducted in the small research tunnels. But these tunnels are not adequate to address the configuration aerodynamics challenges of developing the SLS design database. (Refer to section 2.4.2 for a more detailed explanation of this difference.) Figure 4 shows the various wind tunnels that comprise the aerodynamics asset group.

(ATP supported , Large Facilities)



Vertical Spin Tunnel
Dynamic Stability
& 12' tunnel , B644-646



14x22 by 22-Foot Subsonic Tunnel
Subsonic, Alternate Uses
B1212



National Transonic Facility
High Reynolds Number Flow
B1236



Transonic Dynamics Tunnel
Aeroelasticity & Flutter
B648



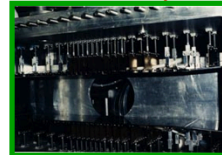
LaRC Unitary Plan
Wind Tunnel (2 legs, B1251)



(not ATP supported, Small Facilities, research tunnels)



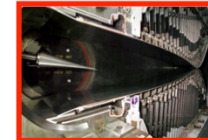
Basic Aerodynamics
Research (BART, B1214)



0.3 Meter Transonic
Cryogenic tunnel
(B1242)



6"x10" Supersonic
Low-Disturbance
(SLDT, B1247D)



20-In Supersonic
(SWT, B1247D)

- Large Facilities (ATP) provide capability to address integrated configuration/concept testing suitable for aerodynamic/aeroacoustics research including propulsion induced effects, and code validation.
- Small Facilities (non ATP) provide complementary capability for component and unit-problem testing more suitable for exploratory research, fundamental flow physics research, and basic code development and validation activities
- Vertical spin tunnel provides stability tests of dynamically scaled aircraft and spacecraft (also see Flight Dynamics and Controls Labs)
- The 14x22 offers multiple and diverse testing capabilities that are not available in any other single facility.
- NTF provides flight Reynolds number test capability that can only be closely matched by ETW.
- TDT provides world-unique aeroelastic scaling test capabilities; also planetary atmosphere simulation
- UPWT has the highest available high pressure air and mass flow for simulating jet exhaust and plume interaction at supersonic speeds.
- Current modifications to 14x22 will extend open test section aeroacoustic testing capability beyond rotorcraft.

Figure 4 wind tunnels comprising the Aerodynamics asset grouping (ATP refers to the ARMD Aeronautics Test Program which is an element of the agency strategic capability asset program (SCAP))

A brief description of the composition of the aerodynamics asset group will illustrate the different mission and capability of these tunnels.

- Large Facilities (ATP) provide capability to address integrated configuration/concept testing suitable for aerodynamic/aeroacoustics research including propulsion induced effects, and code validation.
- Small Facilities (non ATP) provide complementary capability for component and unit-problem testing more suitable for exploratory research, fundamental flow physics research, and basic code development and validation activities
- Vertical spin tunnel provides stability tests of dynamically scaled aircraft and spacecraft
- The 14x22 offers multiple and diverse testing capabilities that are not available in any other single facility, including a unique phased array system for aeroacoustics measurements and a rotorcraft test cell for testing rotorcraft models in simulated forward flight.
- NTF provides flight Reynolds number test capability that can only be closely matched by ETW in Germany. The NTF provides the highest Reynolds number capability of any tunnel, worldwide.
- TDT provides world-unique aeroelastic scaling test capabilities; and also uses a unique heavy gas test environment to simulate planetary atmospheres such as Mars for EDL.
- UPWT has the highest available high pressure air and mass flow for simulating jet exhaust and plume interaction at supersonic speeds.

So it can be observed that the complete set of wind tunnels comprising the LaRC aerodynamics asset group provide a comprehensive, complementary test capability and without nonessential overlapping capability.

2.5.2 Long-term trends will affect future mission relevance (10-20 years, and beyond)

The LaRC 20-year revitalization plan must address mission relevance well beyond our current program of record. In fact, as the plan calls for new buildings, facilities, and laboratories, the relevance must extend well into the future, perhaps 40-50 years. (As discussed in section 1.3, the agency is already establishing goals for 2055!) Visioning this far into the future is a daunting task, even without the complexity of the accelerating pace of technology development, which is increasing at an exponential rate. It is much like shooting at a moving target at some time well in the future. But that is indeed the task assigned to the ViTAL team. So we must rely on all available information which includes trends that could dramatically alter our future mission. As an illustrative example, there are two trends that will eventually change our need for wind tunnels. The first trend is the growing maturity of our computational fluid dynamics (CFD) modeling and simulation capability. These physics-based computer codes have been rendered to the engineering standard practice and have penetrated deeply into industry practices for routine design development work where the vehicle configuration is well understood. While the current CFD capability is not mature for all applications, the aerodynamics community is embracing the trend that eventually we will have full flight simulation capability and may render wind tunnel testing nonessential for future vehicle development programs. While the outcome is easy to predict the timeline is much more difficult. Figure 5 below illustrates one likely timeline that could be achieved with the expected continued increase in computational capability⁴. In discussing this trend, and the expectation of a practical “real time flight simulation” capability by

2035, the uncertainty in the projected time is ± 10 years, depending on assumptions. For example, if quantum computing becomes a reality, when will we be able to affectively harness this vast capability? This could pull up the date to 2025. And of course the date could be much later, depending on the rate of investment over the next decade to complete the development of the CFD codes. The remaining grand challenges include turbulence modeling of separated flows, boundary layer transition, unsteady flow, and aeroacoustics. Currently CFD simulations are too slow to be fully useful in developing aero design databases and there have been no breakthroughs in the last 15 years in CFD algorithm development. A focused investment will be required to accelerate the time to achieve full maturation of the current CFD codes⁵.

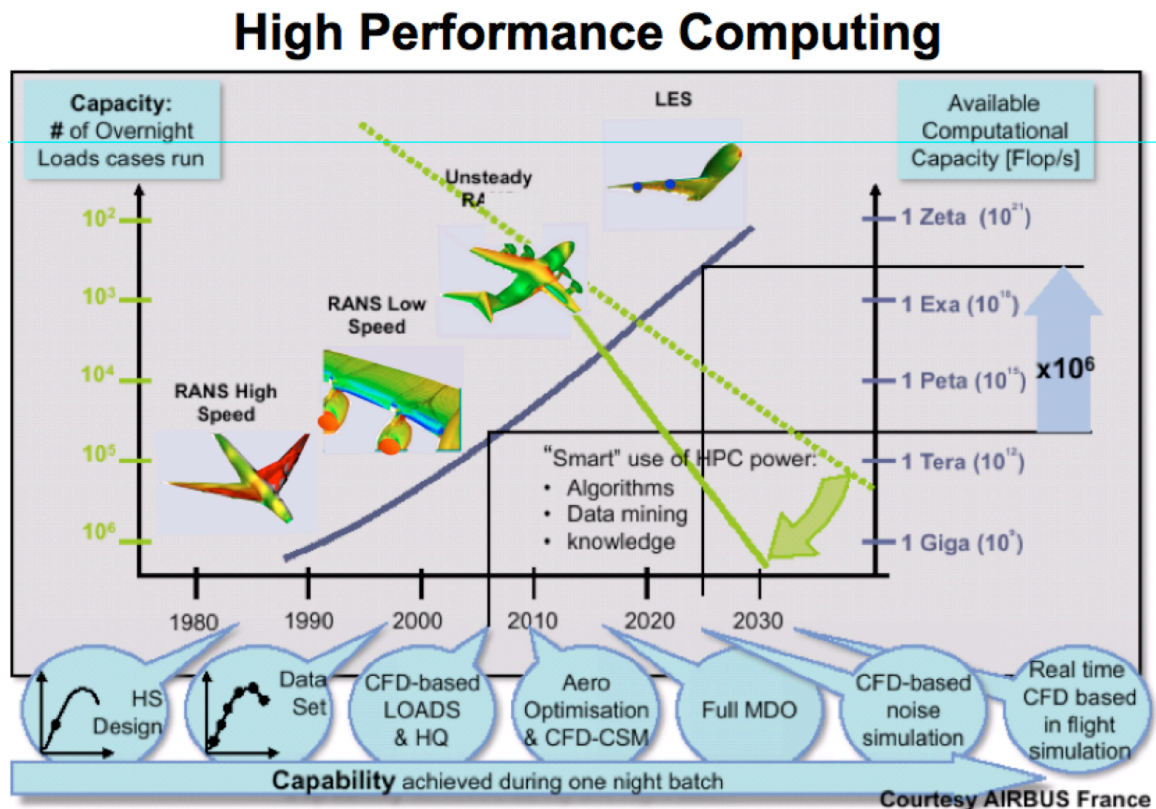


Figure 5 trend in high performance computing illustrated for computational fluid dynamics (CFD)

There is a second trend that is also affecting our need for wind tunnels. That trend, illustrated in Figure 6 is the trend in wind tunnel tests being conducted¹. The dramatic reduction in testing illustrated in Figure 6 is partly due to the increased use of CFD, and partly due to the limited number of new vehicles being developed relative to earlier times in our history when most of the current wind tunnels were constructed.

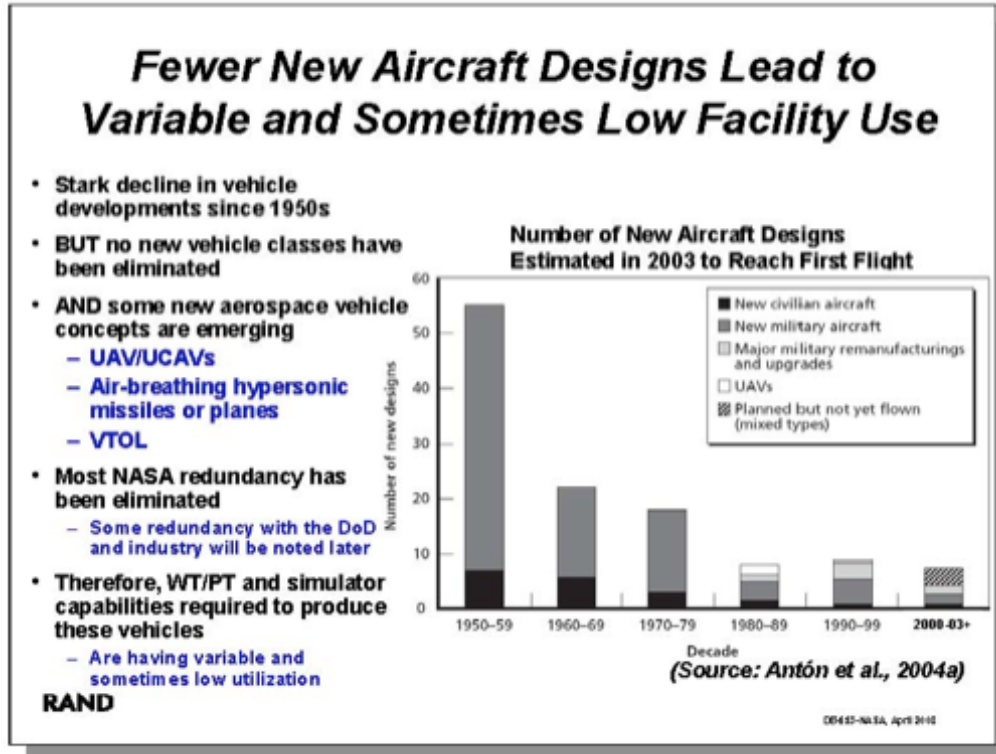


Figure 6 trend in wind tunnel tests being conducted for new vehicle design/development programs

These two trends taken together strongly imply that the future need for large-scale wind tunnels will diminish over time. As illustrated in Figure 6, this trend has been on-going for several decades. So the future need for wind tunnels must be established to meet future mission requirements, rather than the value proposition being based on past usage and current programmatic requirements.

2.6 Integrated strategy: the decision-making framework

Using the wind tunnel trend just cited as an illustrative example, it becomes obvious that the integrated facility and laboratory strategy must be robust and enduring. It must provide for a decision-making framework that allows current and future center and agency leaders to make fully informed decisions as we evaluate the disposition of each asset in the center inventory. While the mission-enabling functions of each of the 17 asset groupings are somewhat different, the decision-making framework for each asset grouping will have some common characteristics. First, it must capture the full spectrum of future mission technical challenges and test requirements. Second, the role of each unique capability in the asset group must be tied to the future mission. Third, the decision-making framework must differentiate fundamental differences such as low TRL foundational research from high TRL vehicle development. Fourth, the framework must identify the viable options for dispositioning each asset and also identify gaps that need to be filled by new assets. Fifth, the framework must find a meaningful way of

addressing the risk to mission success for each option identified. And sixth, the framework must identify key decision points (KDPs) that current and future decision-makers will encounter. As an illustrative example of the process, the decision-making framework for the wind tunnels comprising the aerodynamics asset group is displayed graphically in Figure 7. Once again the wind tunnels are used as the illustrative example.

The logic illustrated in Figure 7 is specialized for the Langley wind tunnels, and a similar decision-making framework was constructed for each of the 17 asset groups listed in Section 2.2. A further explanation of the logic applied to the wind tunnels will provide additional clarity to how the decision-making framework was developed. First, the top box lists the Technical Challenges and Test Requirements identified for the Langley wind tunnels from the future visioning studies. Each wind tunnel in the Aerodynamics Asset Group was mapped against these future requirements. Also, the co-dependencies to other Langley assets are also identified. (These co-dependencies refer to other asset groups among the 17 included in the strategic framework.) Referring to the boxes below the requirements box, the numbers in the brackets after each wind tunnel specifies the requirements addressed by each tunnel. Notice that in each speed regime (subsonic, transonic, and supersonic) there are multiple tunnels in the inventory, each tunnel meets multiple requirements, and further, multiple tunnels may meet the same requirement. So it becomes obvious that there is not a unique one-to-one relationship between a single tunnel and a specific future requirement. A further differentiation was then developed. Three fundamentally different missions were identified – research (low TRL, typically 1-4 to enable the future NASA mission), development (technology development, TRL 4-7, and vehicle development, TRL 8-9, to enable the future NASA mission), and production testing. In this case, production testing refers to company-specific, competitive and proprietary, product development tests in which the tunnel operational expenses will be reimbursed to NASA on a full cost basis. Using this differentiation, the tunnels in each mission area are further identified, along with the missions supported, including the Aeronautics Research Mission Directorate (ARMD), Human Exploration and Operations Mission Directorate (HEOMD), Space Technology Program (STP) and collaborative programs with external partners referred to as work-for-others (WFO). Important questions that may require future key decisions (KDPs) were identified along with options. The KDPs are highlighted by the blue circles with the white numbers and are described in the next paragraph. Below each option, written in the green font, is the implication to mission execution and how the risk to mission success will be mitigated, for example establishing partnerships with other facility operators. Completing this particular decision-making framework is the “Production Testing” assessment, the logic flow shown in the far left of the figure. Note that this line is connected by a dashed line which is meant to indicate that the Langley tunnels were not designed for production testing, but rather for the agency’s research and development mission needs. In order to capture production test business, upgrades will be required to address industry feedback about tunnel flow quality and test data productivity. As this line of work will require industry funding on a full cost reimbursable basis, it is logical to first conduct a market survey to determine if there is a viable business base to justify the government investment in the tunnel upgrades. Key decisions can then be made once the market survey and customer assessments are completed. (See KDP #2 below for more details.)

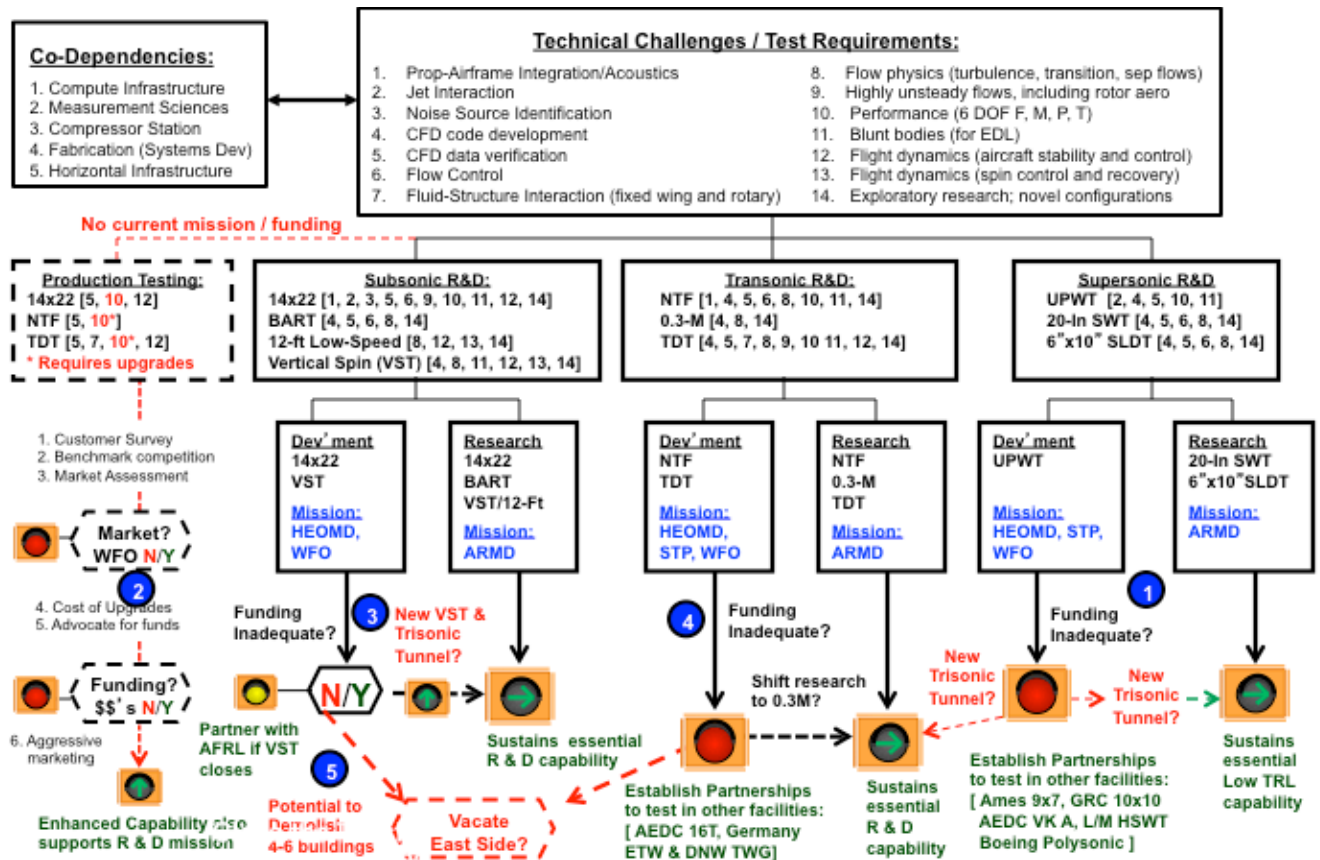


Figure 7 decision-making framework for the wind tunnels in the aerodynamics asset grouping

The logic framework illustrated above in Figure 7 may at first glance appear both complex and arbitrary. However, the usefulness of the framework is best illustrated by how the final details of the 20-year revitalization plan addressed each KDP. There are five KDPs identified for the wind tunnels in the aerodynamics asset group. The KDPs should be thought of as setting up a series of “if-then” conditions, meaning if conditions develop over time that require a specific decision, then these are the options, the investments required, and the impact to mission execution. The KDPs for the wind tunnels in the aerodynamics asset group along with options are defined as follows:

1. Project, ATP, and Reimbursable funds inadequate to operate and maintain the UPWT; advocate for funding to sustain essential supersonic research experimental capability;
 - Option A: upgrade test capability in existing supersonic research tunnels. ROM~\$1.65M for new nozzle plate, upgrade nozzle position control system, replace Vicker controllers, upgrade balance and data system.
 - Option B: Compressible Aerodynamic Research Tunnel (CART) studies have been conducted in the past decade. CART has a variable test section to support subsonic, transonic, and limited supersonic capability research with efficient two-person operations. Several CART options were identified. Small-scale, minimal capability subsonic, ROM~\$20M; Small-scale, maximum capability trisonic,

ROM~\$100M, which also provides aeroacoustics research but with limited capability for configuration/concept studies; also investigate repurposing parts of UPWT to off-set cost of CART.

2. Market assessment supports a viable external “Production Testing” reimbursable funding stream to help sustain tunnels [Market assessment identifies reimbursable production tests business only for 14x22, NTF, and TDT tunnels. However, upgrades to the 14x22, NTF and TDT will be required to address customer concerns about data quality, tunnel reliability, and productivity. ROM estimates for 14x22 is \$4.5M for DAS upgrade; NTF upgrades is \$1.8M (DAS improvements, flow control cal, test section access, mach control, model support, insulation); TDT upgrades ROM~ \$18M (\$4.5M DAS, \$5.3M exterior painting, \$4m oscillating vane, \$3m pressurization upgrade system, \$0.5M elevator floor, \$0.250M customer workspace)

3. Project, ATP, and Reimbursable funds inadequate to operate and maintain the NTF and/or TDT

Option A: close NTF; partner for high Re# development tests and integrated configuration research (EU ETW in Germany); replicating high precision drag/laminar flow and flow control tests will require modifications to Ames 11 ft; not viable to upgrade TDT to replace NTF; no other comparable large scale high Re# testing capability in the U.S.; marginal research capability exist in 0.3M cryogenic transonic tunnel; additional research capability from new trisonic option KDP 1.1, Option B

Option B: close TDT, partner for aeroelasticity development tests (Ames 11 ft, AEDC 16T, and EU DNW LLS), upgrades will be required; marginal research capability exist in 0.3M and NTF, but will have to install safety infrastructure; additional research capability from new trisonic tunnel option KDP 1.1, Option B; not viable to upgrade NTF to expand aeroelasticity research capability; closing TDT will result in lost national aeroelastic research capability unless another heavy-gas facility of suitable scale is built

4. Project, ATP, and Reimbursable funds inadequate to operate and maintain the Vertical Spin Tunnel, consider run-to-failure or relocate on West Side adjacent to 14x22 to reduce cost of ownership, ROM estimate from ~\$5M to relocate the VST

5. Vacate the LaRC East Side, co-located with the LAFB and in a flood plane:

Option A: Capital investments support building a new Vertical Spin Tunnel or relocating existing VST adjacent to the 14x22; ROM estimates range from ~\$5M to relocate the VST and achieve modest upgrades to \$20M-\$30M with options on the scale of a new VST with enhanced capability.

Option B: then vacate the East Side if the Transonic Dynamics Tunnel is placed in mothball status.

A decision-tree framework like the one above for the wind tunnels was developed for each of the 17 asset groups listed in section 2.2. The ViTAL team then used the FOMs, section

2.3, and dispositioned each KDP to develop the integrated plan. The completed details may be found in Appendix A. Later chapters in this report provide the details of the revitalization plan which reflect the disposition of the KDPs for each asset group. To illustrate this outcome, Figure 8 below overlays the KDPs in Figure 7 with the decisions rendered by the ViTAL team and captured in the 20-year revitalization plan.

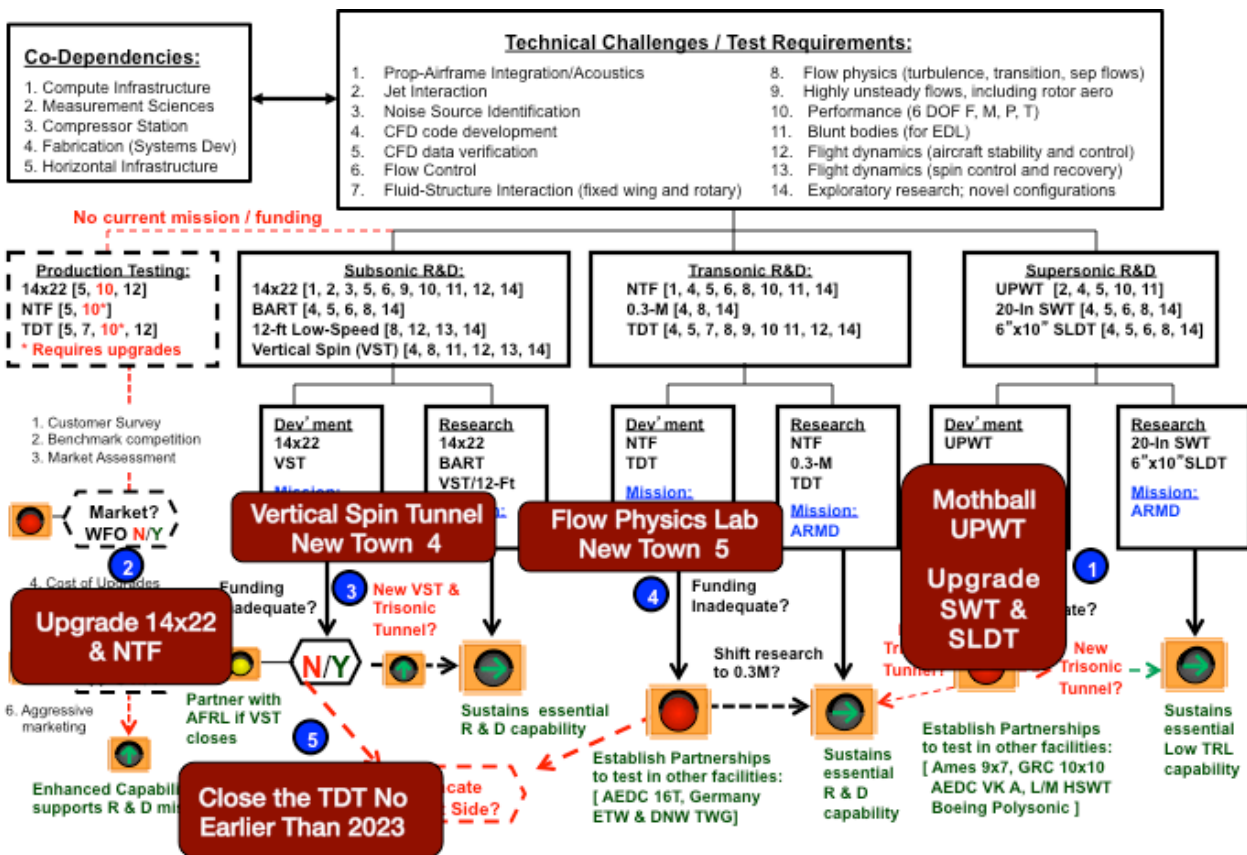


Figure 8 decisions regarding the future of the Langley wind tunnels (“New Town” refers to the new building phases of the revitalization plan, the terminology was officially incorporated into the Center Facility Master Plan in 2010)

2.7 Summary

A summary of the key attributes of the 17 asset groups is provided in the table in Figure 9. While reviewing this table, it should be remembered that in each asset group there are several ground test facilities and research laboratories. Some explanations of the tabulated information will assist the reader. Also note that the high pressure air compressor station, electrical distribution infrastructure and other essential horizontal infrastructure, and compute infrastructure are not listed.

LOE: Gr-high, Y-med, R-low, Wh~N									
Asset	Attribute	Some Uniqueness (blue) Standard, easily duplicated	Cost of Ownership line 1: M&U Line 2: DM	State Of Infrastructure (Rd, Yw, Gr)	State Of Equipment	NASA Mission Relevance - ARMD -	NASA Mission Relevance HEOMD/STP	NASA Mission Relevance - SMD -	Reimbursable Opportunities
Materials & Structures	COLTS, LandIR		\$3.30M \$14.7M	NT 4	LandIR CPC			EDL Inflatables	Industry
Measurement Sciences (flow physics)			\$1.09M \$7.28M	B1230					
Acoustics	14x22, Liner, TAFa, psycho lab		\$1.19M \$8.73M	NT 5					Industry, DOD
Aerodynamics	NTF, TDT, 14x22 (SRW)		\$8.59M \$66.0M	NT 5	TDT DAS			EDL	Industry, CCDEV
Aerothermodynamics	LAL		\$1.42M \$9.08M	B1247		EDL	EDL	EDL	CCDEV
Hypersonic Airbreathing Prop	8' HTT		\$1.60M \$11.2M	B1247	B1221				DOD
Flight Dynamics & Controls	VST		\$0.36M \$1.42M	NT4				EDL	CCDEV, DOD
Crew Systems & Aviation Operations	ATOL		\$0.56M \$1.88M	B1268					FAA
Electromagnetics and software-intense Fit Sys			\$0.65M \$2.89M	NT 3					Industry
Sensor Systems			\$0.24M \$0.76M	NT 3					NOAA
Environmental Testing Laboratories (Sys Dev)			\$0.56M \$1.33M	NT 6					NOAA
Simulators			\$0.36M \$0.87M	No rec'd actions					FAA
Langley Aircraft			\$0.99M \$2.69M	No rec'd actions					DOD, FAA, EPA
Fabrication (Sys Dev)			\$1.18M \$2.22M	NT 4&6					
Science Laboratories			\$0.65M \$0.55M	NT 6					NOAA

Figure 9 Summary table showing all asset groups, cost of ownership, and relevance to the NASA mission

The second column provides an assessment of the **uniqueness** of the assets. A simple two-level differentiation was employed. “Some uniqueness” refers to capability that is unique to the agency, in some cases unique to the nation, and unique to the worldwide technical community. For example, several of the wind tunnels in Aerodynamics are listed with unique capability. The National Transonic Facility (NTF) uses liquid nitrogen as the test medium and can achieve the highest test condition Reynolds Number of any tunnel in the world and is the only high speed tunnel that matches flight Reynolds Number conditions. The Transonic Dynamics Tunnel (TDT) is a unique tunnel originally designed and specially constructed to conduct aeroelasticity and flutter clearance testing. This unique test capability requires the use of flexible models that change shape in response to and interact with the flow conditions. Special care must be taken in testing so that a model failure does not destroy the tunnel. In addition, to simulate the dynamic pressures that give rise to structural instability, a variable pressure and heavy gas system is required to fully simulate the flight conditions that an aircraft may experience. Finally, the 14’x22’ large test section low speed subsonic tunnel has several unique test capabilities. One unique capability is the ability to conduct rotorcraft aerodynamics by simultaneously simulating rotor blade rotation and forward flight. The second unique test

capability a novel phased array system on a moveable traverse system allows for aeroacoustic testing that provides the ability to isolate and characterize the individual sources of noise from a test model. This is particularly important when addressing propulsion/airframe integration noise issues.

The second column also designates (by omission of the blue box background) capability that is **standard** in most similar laboratories and may be considered easy to duplicate. This is attributed to the fact that most research laboratories are a collection of standard scientific measurement instruments, for example, which in many cases are commodities that can be purchased from equipment vendors. A final useful qualitative interpretation of the data in the second column is that unique capability may be difficult and expensive to sustain and reconstitute once abandoned, but standard capability is relatively easy to duplicate, enhance or reconstitute.

The third column tabulates data to assess the **Cost of Ownership** for each asset group. Two data are tabulated. The top line in each box is the three-year average of the annual maintenance and utility (M&U) costs to operate the assets. The second line in each box is the deferred maintenance (DM) which is compiled using the standard agency method for estimation. DM may also be thought of as risk-to-mission, meaning that without proper maintenance a facility may be in marginal operational condition or even obsolete so that an unexpected breakdown resulting in a lengthy and costly repair that would jeopardize timely and successful completion of a critical agency project milestone. While these data are self-explanatory, it must be pointed out that the cost of ownership for the Aerodynamics assets, primarily the large wind tunnels, is far greater than any other LaRC asset group. A final reasonable interpretation of these data is that both yearly cost savings (from M&U) as well as future budget liens (DM) are accrued yearly and will aggregate over time whenever a facility or building is closed and abandoned.

The fourth column provides a qualitative assessment of the **state of the infrastructure**. A green, yellow, red stoplight color coding was adopted for the assessment. Green means good/great conditions, whereas red means inadequate - immediate actions required, while yellow designates "at risk" marginal condition. It should be noted that a strategy of run-to-failure would eventually render an asset as marginal or yellow. Additionally, each yellow or red box in column four has an overlaid brown-red box with a shorthand reference to an element of the 20-year revitalization plan, where the intent of the plan is to adequately address all at-risk, essential capability to assure that the assets will be available to execute the future NASA mission as required. The fifth column provides a similar assessment of the **state of the equipment** found within each asset group. In most cases the equipment in the LaRC research laboratories are in good condition.

The right-most four columns attempt to assess the level of **relevance** to the current and future programs of the NASA mission directorates, including an assessment of the likelihood for reimbursable funding from external customers who may need to use our facilities in cases consistent with the NASA policy guidance on non-NASA work. For these four columns, the red-yellow-green color coding is intended to convey different information than the colors of the state of infrastructure and equipment columns. The intent for relevance is to capture an objective measure of the demand or need for the asset to enable the agency mission. Green should be

interpreted as robust and critical, yellow as medium, and red indicates a relatively low level of effort to meet mission requirements. In this case red is not a negative color, rather it is relative to the robustness of green. It is tempting to interpret the colors as meaning “essential” versus “nice to have”, but this oversimplifies the relevance. In many cases, the asset group contains the ordinary tools that are used to execute the work. Without these tools the work must be accomplished differently. One critical value judgment from the relevance data is that if an asset is not at least green for one NASA mission, then the future of that asset will be uncertain.

The complete details of the integrated strategy for the 14 primary asset groups and the 3 co-dependent support asset groups may be found in Appendix A. The remaining chapters of this report document the elements of the 20-year revitalization plan, the implementation strategy, and the project management process to be followed to guide implementation.

2.8 References

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3.0 Revitalization Projects

3.1 Introduction

The Langley 20-Year Revitalization Plan is comprised of 10 projects including the 6 New Town building phases, 3 building Rehab projects, and 1 project comprised of multiple wind tunnel research facility upgrades. The 6 New Town buildings will be funded by the agency Recapitalization Fund and will include both new building construction and the associated demolition of many obsolete buildings. New Town Building 1 was completed and occupied in 2011 and is included in this new plan for completeness. The 5 additional New Town building phases, New Town 2, 3, 4a and 4b, 5, and 6 will begin in years 2012, 2015, 2018, 2023, and 2028, respectively. The 3 building Rehab projects will be funded by the agency Construction of Facilities (CoF) Fund. These CoF projects include rehabs to buildings 1230 and 1194, in 2014 and 2017, respectively, and a phased project with CoF funds over multiple years to upgrade the compressor station and electrical distribution system in years 2014-2018. The wind tunnel facility upgrades will be funded by a combination of Center CMO funds and project funds. The activities of these 10 projects have been time-phased so that any obsolete facility or office space will not be vacated until the new/rehab/upgraded facilities or office space is rendered ready for use or occupancy. The completion of the entire plan is expected to be achieved in 2032. Each of the 10 projects is described below, sections 3.2 to 3.11, in chronological order, along with the accompanying details. Note that the year of project initiation and status of funding is provided in the **blue font** parentheses after each project title. Section 3.13 is a summary of the disposition of every Key Decision Point (KDP), as discussed in section 2.6.

3.2 New Town Phase 1 (NT1) – Langley Headquarters Building (2011, occupied)

3.2.1 Project Overview

The first project in the New Town Program is the Langley Headquarters Building. This design-build project was completed in 2011, see Figure 10, with a design, construction, and outfitting cost of about \$34M. Design and construction was funded by NASA's Recapitalization Program and outfitting was funded by Langley's CMO budget. The Langley Headquarters Building is a 3-story, 79,000 sq. ft. office facility, which incorporates up to 250 occupants, including the Center Director's office and 5 other support offices. It was the first

large office building to be constructed on the LaRC campus in over 35 years. Being near the main entrance and incorporating the Langley Center Director's office, it is a very visible component of the long-term facilities modernization program. Because this facility was built on a green field location, no demolition projects were required on the building site. However 148,000 sq. ft. of old, inefficient space was demolished elsewhere on the center in support of this project, yielding a 69,000 sq. ft. net increase in available green space. Demolishing a large quantity of inefficient space and then replacing it with smaller more efficient space significantly reduces the Center's infrastructure costs. The building includes many sustainability features, which contribute to the overall sustainability goals of the Center, and saving or avoiding \$2.5M per year in operations and maintenance costs. This project was awarded the LEED Platinum Certification by the U.S. Green Building Council in June 2011. This project was implemented by an integrated project management team including NASA, GSA, and GSA contractors through an interagency agreement with GSA. NASA and GSA co-managed the project and provided direction. All of the prime contracts were awarded and managed by GSA.



Figure 10 New Town Building 1

3.3 New Town Phase 2 (NT2) – Integrated Engineering Services Building (2012 groundbreaking, funded by agency Recapitalization Program)

3.3.1 Project Overview

The New Town Phase 2 building is fully funded and is in the process of being designed and constructed. Figure 11 provides a summary of the project details for New Town 2 and Figure 12 provides an artist rendering of the building. It is scheduled to be completed in January 2014 and relocations into the facility completed in April 2014. The building will become the engineering and research collaboration center and it will include an integrated design center, flight mission support center, conferencing facilities, training, video production/editing, and food services. This building is located at the center of the campus to encourage walking to and from

this facility. The new building will be a 2-story 137,000 sq. ft. modern facility, designed to a LEED gold certification. Parking for this facility will be both adjacent to the building and across the street adjacent to B1146.

FY Start	Description	Justification (Demo's No Earlier Than)	Cost Savings (\$M)
2012	Integrated Engineering Services Building: Engineering Design Center, Flight Mission Support Center, Collaboration and Cafeteria	Relevant to all MDs; Core Campus; Demo B1192 (all), B1213, B1222, B1145 and B1298	M+U: \$0.86 DM: \$2.0 CRV: \$45.7

Figure 11 Summary of New Town 2 Project Details

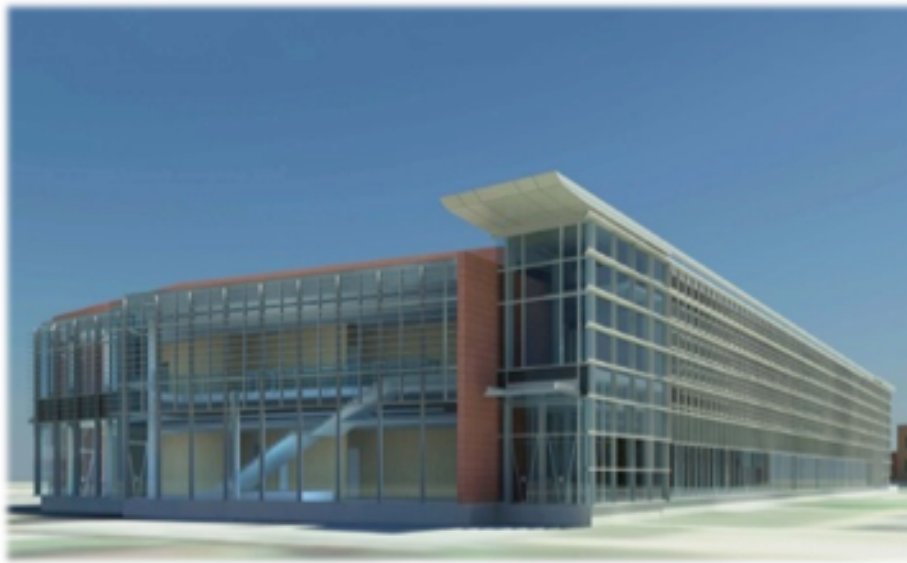


Figure 12 Artist rendering of New Town building 2

3.3.2 Construction

Using an interagency agreement with GSA, a design-build contract was awarded in January 2012 using funds from NASA's Recapitalization Program. The notice-to-proceed was issued in late February 2012 and the contract duration is 23 months. The final design work is approximately 50% complete and construction work on the site is in its early stages. The estimated design, construction, and outfitting cost is \$50M.

3.3.3 Demolition

The demolition includes four buildings on the construction site: Buildings 1149, 1141, 1152, and 1153 (demolished in 2011) and 5 buildings whose functions are moving into the New Town 2 building. These are Buildings 1192, 1213, 1222, 1145 and 1298. The total area of the last group of building is 133,000 sq. ft. Also, since this building consolidates many functions scattered throughout the center, there are pockets of space in other buildings that can be repurposed and reused.

3.4 B1247 Wind Tunnel Facility Projects (2012, and as funds become available)

3.4.1 Project overview

This project includes upgrading the capability of 5 wind tunnels located in the B1247 complex and upgrading and relocating the Small Anechoic Jet Facility from B1221 to B1247. The details of the project are summarized in Figure 13 and a detailed discussion on each facility follows in sections 3.4.2 to 3.4.7 below. While the primary motivation for these upgrades is to improve the existing test capability of these assets, a second primary motivation is to satisfy precursor conditions to vacating the assets in B1221, B1275, and eventually B1251. The CF4 gas tunnel in B1275 will be abandoned, as will the direct connect and combustion heated scramjets in B1221 after the upgrade to the arc heated scram jet facility in B1247. It should be noted that once B1221 is vacated the Center will not have a suitable replacement for the Low Speed Aeroacoustic Wind Tunnel (LSAWT, sometimes referred to as the jet noise lab). However, a similar facility exists at NASA Glenn Research Center, the Aero-Acoustic Propulsion Lab (AAPL), where the Langley led testing can be facilitated. [While there are similarities between the AAPL and the LSAWT, there are also significant differences. These differences include the maximum temperatures attainable by the facilities (1425 F in the AAPL and 2000 F in the LSAWT), the LSAWT is an open circuit wind tunnel with an open jet test section surrounded by a secure anechoic chamber that is smaller than the AAPL dome, and the LSAWT is not restricted to jet noise testing, for example the Jet Engine Simulator can be replaced with a propeller test stand.] In the long-term, the expectation is that the new flow physics laboratory, section 3.10, will include a mid-size aeroacoustic research capability. The B1247 project also includes a new high Reynolds Number aerothermodynamic test capability to be realized in B1247 that will exceed the test capability of the 31” Mach 10 tunnel in B1251 and perhaps the 20” Mach 6 tunnel in B1247. This development coupled with the decision to close the Unitary Plan Wind Tunnel in B1251 will allow the abandonment of B1251. After completion of this project, the center will save approximately \$1.1M annually in reduced facility maintenance and utility costs and dramatically reduce the Center’s deferred maintenance (\$14M) and CRV (\$134.6 M) as indicated in Figure 13. Finally, FY12 Center investment funds have already been allocated for several of these tunnel upgrades.

FY Start	Description	Justification (Demo's No Earlier Than)	Cost Savings (\$M)
2013	Facility Upgrade B1247: Consolidate and repurpose three research wind tunnels to compliment/ enhance Supersonic and Hypersonic research capability	Core campus; <i>Precursor to demo of B1251</i> ; Demo B1221 and B1275; ARMD and moderate HEOMD and STP relevance	M+U: \$1.1 DM: \$14.0 CRV: \$134.6

Figure 13 Summary of Project Details for Wind Tunnel Upgrades

3.4.2 20 inch Supersonic Wind Tunnel (upgrade)

Two modifications are being made to the 20 inch Supersonic Wind Tunnel. The first modification is the replacement of a defective nozzle plate. The defective top nozzle plate causes a disturbance in the flow that limits the useful space of the test section. This limits the size of the model, thereby limiting the model Reynolds number that can be tested. The new plate will make the entire test core available. The second modification is an upgrade of the Vickers controllers. These controllers are used to control the tunnel second minimum and the model support system. The controllers are antiquated and out of production. Failure of these controllers would mean the facility would be unable to run.

Funding has been provided in FY12 to begin the upgrades with completion anticipated in FY13. Detailed measurements and drawing refinements have been initiated. An assessment of the heat treat facility/process detailed requirements is also underway. For the Vickers controllers replacement, information is being gathered to identify detailed requirements of replacement units with sufficient performance and interface capability.

3.4.3 Supersonic Low Disturbance Tunnel (upgrade)

The control room of the Supersonic Low Disturbance tunnel is being upgraded to use modern controls and monitoring systems that provide all tunnel settings and parameters to the data acquisition systems. To achieve and maintain quiet flow in the facility, all aspects of the facility operation must be monitored and recorded. These modifications will improve the productivity and reliability of the facility. Several years ago, the Supersonics project funded an engineering design study to define the details of the upgrade to the control room. The FY12 center funds are being used to complete the implementation of the upgrade. Currently, the previous ROME design is being reviewed to make sure all changes identified in the 2008 CDR will be addressed and to verify the compatibility of the design with the facility changes that have occurred since 2008. System components have been identified and procurement actions have been initiated. The task to verify the facility electrical drawings and convert the existing drawings to CAD has been initiated. Programming continues for the PanelView displays to be used by facility operators. These new displays will be demonstrated and reviewed by the facility operators to make sure all necessary information is organized and displayed in a manner that will enhance facility operations.

3.4.4 Mach 6 Quiet Tunnel (renovation)

The renovation of the Mach 6 Quiet Tunnel will provide Langley with a facility to investigate the fundamental physics of hypersonic boundary layer transition. High speed quiet tunnels were developed at Langley after it was discovered that the turbulent boundary layers on conventional supersonic and hypersonic wind tunnel nozzles were generating acoustic disturbances that caused boundary layer transition to occur earlier than it would in flight. Langley currently operates the only supersonic quiet tunnel and has been leading the field in pioneering off-body measurements of boundary layer instabilities. However, as the Mach number increases, above approximately $M \sim 4.5$, there is a fundamental change in the boundary layer stability characteristics. Thus, in order to understand and predict transition at higher Mach numbers, a higher speed quiet facility is required. Previously, Langley built and operated the Mach 6 Pilot Quiet Tunnel; and leveraging this experience, design requirements are being developed to modify the existing Nozzle Test Facility to create a fully operational Mach 6 Quiet Tunnel. The Langley Flow Physics Branch personnel will use CFD to develop the aerodynamic design for the new nozzle geometry for the quiet tunnel.

3.4.5 Hypersonic, High Reynolds Number Tunnel (repurposing the Mach 8 VDT)

The 20-Year Revitalization Plan proposes to create a new Hypersonic, High-Reynolds Number Tunnel (HHRNT) by renovating and repurposing the assets of the Mach 8 Variable Density Tunnel currently abandoned in place in B1247. The HHRNT will be capable of operation at multiple Mach numbers (notionally 6, 8, and 10), via either interchangeable nozzles or separate legs, and will generate a wide range of Reynolds numbers sufficient to produce laminar, transitional, or turbulent flow at each Mach number. Notional Reynolds number ranges (assuming a minimum 16-in test core) at each Mach number will be $2 \times 10^6/\text{ft}$ to $20 \times 10^6/\text{ft}$ at Mach 6, $4 \times 10^6/\text{ft}$ to $16 \times 10^6/\text{ft}$ at Mach 8, and $0.5 \times 10^6/\text{ft}$ to $4 \times 10^6/\text{ft}$ at Mach 10. This wide range of test conditions is necessary because aerothermodynamic phenomena such as shock-shock interactions, boundary-layer transition, deflected control surface aerodynamics, thruster-flowfield interactions, etc, are both Mach and Reynolds number dependent.

The HHRNT will feature a large test section with abundant optical access for global measurement techniques (i.e. global phosphor thermography and infrared photography for surface heating and boundary-layer transition and PLIF and schlieren for flow-field visualization); a dynamic, precision-controlled, multi-axis model support and positioning system for aerodynamic force and moment testing that includes both water cooling and gas-injection capabilities; and high-frequency data-acquisition systems for sensors and instrumentation (thin-films, thermocouples, pressure modules, hot-wires, etc).

The HHRNT will operate in a flexible mode with the capability of running 6 – 12 times/day over a range of test conditions to enable in-depth studies of complex aerothermodynamic phenomena, development of Computational Fluid Dynamics validation databases, and parametric screening and analyses of proposed hypersonic vehicle configurations. The HHRNT will thus provide a fast-paced Research & Development oriented facility to supplement larger national hypersonic assets operated by DoD that are targeted at production-level Testing & Evaluation programs.

The HHRNT capabilities will supersede those of the current 20-Inch Mach 6 Air Tunnel (in Bldg 1247) and the 31-Inch Mach 10 Air Tunnel (in Bldg. 1251) by a factor of approximately 3 in length-Reynolds number, as well as providing a bridging capability at Mach 8 for which NASA has no equivalent. Thus, following completion and operational performance validation of the facility, the existing facilities could be closed.

Requirements for an engineering study are being formulated in order to determine the infrastructure and design options for the HHRNT and to establish cost metrics on the operational characteristics. Trade-offs to be evaluated include reuse of existing hardware (mainly that of the mothballed 18-Inch Mach 8 Quiet Tunnel in Bldg 1247) vs. fabrication of new components; the feasibility of maintaining the desired test core size and Reynolds number range at each Mach number; implementation of the multiple-Mach number capability through separate legs or interchangeable nozzles, as well as the number of legs to be developed vs. retention of existing facilities; and the use of nitrogen in place of air as the test gas. Pending the results of the engineering study, the revitalization plan will presume that the HHRNT will either be a repurposed Mach 8 tunnel or a new tunnel, if funding permits, that will be located in a vacant test cell in B1247.

3.4.6 Multi-Gas Hypersonic Aerodynamic Tunnel (proposed)

The 20-Year Revitalization Plan recognizes the need for a Multi-Gas, Hypersonic Aerodynamic Tunnel (MGHAT) to support future agency mission work in planetary entry, descent, and landing. However, the plan does not baseline this capability as part of the center investments. Further advocacy for this facility will be required to secure project funding, with the expectation that multiple fund sources will most likely be required for successful advocacy. The MGHAT will be used to study the effects of different planetary atmospheres on the hypersonic aerodynamics of entry vehicle configurations (including force-and-moment measurements, RCS performance and interactions, aeroelasticity of inflatable/deployable aeroshells, etc) at low to moderate Reynolds numbers. The facility will be designed to use a variety of test gases to simulate different planetary and satellite atmospheres; e.g. Air for Earth, CO₂ for Mars/Venus, He for gas giants, CF₄ (for approximation of reacting air), etc. The thermodynamic properties of these gases produce different flow fields at equivalent Mach numbers, which directly affects an entry vehicle's aerodynamics performance.

Operational requirements for this facility are being generated based on input from interested users – primarily the planetary exploration community. The operational Mach-Reynolds number range of this facility will be a function of each test-gas, but focused toward lower hypersonic Mach-Reynolds numbers (e.g. towards peak dynamic pressure on a trajectory) where boundary-layer transition is not an issue, as well as towards lower densities (for better simulation of RCS and thruster performance and interactions).

Component development will be required to develop nozzles suitable for use with each test gas, a model injection system, and gas storage and handling facilities for non-air testing. Where feasible, components from the decommissioned 20-Inch Mach 6 CF₄ Tunnel will be

employed in the development of this facility. The most likely location for the MGHAT will be in a vacant test cell in B1247.

3.4.7 Arc Heated Scramjet Test Facility Upgrade

The Arc-Heated Scramjet Test Facility (AHSTF) will be upgraded to achieve two primary objectives; (1) expand the operating envelope to cover Mach 2.5 to 4 flight simulation in the semi-freejet test mode and (2) improve the flow quality, reduce the test condition uncertainty, and improve test repeatability.

The current AHSTF operating envelope covers Mach 5 to 8 flight (albeit at limited dynamic pressure due to power and pressure limitations) in the semi-free jet test mode (facility nozzle exit condition simulates conditions downstream of vehicle forebody oblique shock waves) utilizing facility nozzles that produce Mach 4.7 and 6 flow at enthalpies corresponding to Mach 5 to 8 flight. The AHSTF is also capable of simulating Mach 5 to 8 flight conditions in the direct-connect test mode (facility nozzle exit condition simulates scramjet combustor entrance conditions). Currently the Combustion Heated Scramjet Test Facility (CHSTF) provides semi-freejet test mode flight simulation in the Mach 3 to 6 range and the Direct Connect Supersonic Combustion Test Facilities (DCSCTF) provides direct connect test mode flight simulation in the Mach 3 to 7 range. The CHSTF and DCSCTF, aka Test Cell 1 & 2, are located in building 1221 which is slated for demolition in the 20 year plan (Section 3.4.1). Thus, expanding the AHSTF operating envelope recovers an experimental capability in the Mach 2.5 to 4 flight simulation range. The required AHSTF upgrades to achieve this capability includes procuring semi-freejet facility nozzles and the associated plenum/mixing chamber, as well as pressure and flow rate upgrades to the air delivery system. Under the current ViTAL budget a minimum of one facility nozzle (for Mach 4 flight simulation) will be procured. As budget allows, an additional facility nozzle for Mach 2.5 flight simulation will be procured. A plenum-nozzle adapter flange will be fabricated to allow existing DCSCTF direct-connect nozzles to be utilized.

Toward the second objective to improve flow quality, reduce test condition uncertainty, and improve test repeatability, the effort will be focused on the expanded lower-Mach simulations because available budget does not support improvements at the existing higher-Mach conditions. The motivation for these improvements is to improve fidelity and to reduce and better quantify experimental uncertainty. While this is important for all experimental objectives the focus is on computational fluid dynamic (CFD) code development, verification and validation. To improve flow quality (reduce undesirable facility nozzle exit flow profile) a new plenum will be designed and fabricated with stricter flow quality requirements, facility nozzle contours will be developed with state of the art design methods and CFD codes, and the nozzle will be designed and material selected to minimize thermal distortion, especially in the throat region. To reduce test condition uncertainty a nozzle exit calibration system consisting of pitot and static pressure and total temperature probes mounted on an automated flow survey apparatus will be procured to allow routine nozzle calibrations. To improve test repeatability an improved math model of the air delivery system will be developed. This will be used to derive requirements for the pressure and flow rate upgrades as well as to develop more repeatable test conditions.

3.4.8 Small Anechoic Jet Facility

The Small Anechoic Jet Facility (SAJF) will be moved from its current location in B1221 into a vacant test cell in B1247. As part of this relocation, the SAJF will be upgraded to expand its capability into a premier, low-TRL jet noise research facility. Currently, the SAJF can only test a single jet stream at limited temperatures due to minimal exhaust fan capability. However, realistic jet engines typically have both a hot core and a cooler bypass stream, characteristics which have a significant impact on jet noise. In addition, the anechoic chamber surrounding the jet apparatus is too small for adequate far-field noise measurements. Thus, the plan is to add a second jet stream while simultaneously enlarging the surrounding anechoic chamber. The planned upgrades also include improvements to the exhaust fan capability by replacing the fan/motor and enlarging the exhaust duct size. This would allow the full capability of the existing core stream heater to be realized and result in a realistic co-flowing flight stream (to simulate forward flight effects). The facility will also need a new data acquisition system and control room. These changes would make SAJF a leader among low-TRL jet noise research facilities. An engineering study will be conducted to determine the infrastructure requirements for the upgraded SAJF and the best location in B1247 for the new facility.

3.5 Rehab B1230 (2014, approved in agency CoF Program)

3.5.1 Project Overview

The personnel and associated laboratories in B1200 dedicated to advanced sensing and optical measurements research will be moved from B1200 into B1230 once that space is renovated. A CoF project for FY14 has been approved pending the FY14 budget appropriation. The details of this project are summarized in Figure 14. Once B1200 is vacated and demolished, the center expects to save \$0.5M annually on building maintenance and utility costs and reduce the center CRV by \$35.8M. Demolishing B1200 will reduce the center footprint by 28,000 sq. ft. and without any increase in footprint.

FY Start	Description	Justification (Demo's No Earlier Than)	Cost Savings (\$M)
2014	Lab: Rehab B1230 for Advanced Sensing and Optical Measurements; Enhance Measurement Sciences Capability (Aerosciences)	Relevant to ARMD with potential application to HEOMD, STP & SMD; Core campus; Demo B1200	M+U: \$0.5 DM: \$4.4 CRV: \$35.8

Figure 14 Summary of Project Details for B1230 Rehab

3.6 Upgrades to Compressor Station and Electrical Distribution Infrastructure (2014-2018, in CoF advocacy)

3.6.1 Project Overview

The center will advocate for CoF funding to upgrade the compressor station and electrical distribution system infrastructure. See figure 15.

FY Start	Description	Justification (Demo's No Earlier Than)	Cost Savings (\$M)
2014-18	Infrastructure: Electrical Distribution	Relevant to all MDs; address aging electrical infrastructure	N/A
2015	Infrastructure: Compressor Station Rehab	Relevant to all MDs; address aging infrastructure/ compressor reliability issues	N/A

Figure 15 Summary of Project Details for Compressor Station and Electrical Distribution System Upgrades

3.6.2 Compressor station

Since 2004, LaRC has invested an average of \$3M per year in maintenance and utility (M&U) funding on a variety of Compressor Station projects addressing structural damage in the foundation, compressor refurbishment, and equipment replacement. However, the results of these projects are at best unclear as the operation log for 2008-2010 indicates that at no time were there more than 3 of 6 compressors in operation, and for the *majority* of the operations since April 2008, the Compressor Station has been generating high pressure air using only one compressor at a time with no available backup, resulting in a high risk of not being able to meet requested air demands. At times when only one compressor was operational, 3rd shift operations were utilized to keep up with air supply demands.

Investments since 2004 have improved reliability, and analysis shows that the mean time between failures (MTBF) for the combined compressor systems increased from 37 hours in 2005 to 134 hours by the end of 2010. Although noteworthy, this improvement is more than an order of magnitude lower than the MTBF of a new compressor (2400-2600 hours). Furthermore, the notion that the compressors can last indefinitely, if well maintained and continually upgraded, is not credible because the existing equipment is operating well past its design life. Maintenance and repair costs will continue to escalate due to increasing failure rates and extended downtimes are expected due to obsolete equipment and unobtainable parts.

Given the occurrence of high-cost failures, even following compressor overhauls, future major failures should be anticipated if the compressors are not replaced. The NASA Safety Center (NSC) studied this issue for Langley and recommends a multi-phase compressor

replacement strategy which will lead to sustainable operations through significant improvements in reliability, availability, and the probability of meeting the air demand. The NSC analysis shows that investing in new compressors will significantly increase the system availability, reliability, and capacity, which in turn will increase the ability to meet air demand. Expressed in terms of a reduction in the probability of failing to meet demand (1 in 5 days to 1 in 37 days), the improvement is about 700 percent. Similarly, a compressor replacement strategy will improve the operational availability of the facility more than 1000 percent, expressed as a reduction in system unavailability (1 in 40 to 1 in 500 days).

The revitalization plan calls for a CoF project to replace the current compressor station infrastructure in a phased approach consistent with likely yearly funding available in the agency CoF program. The cost of the Phase 1 investment is estimated at \$15M, with each additional phase estimated at approximately \$12M.

3.6.3 Electrical Distribution System

LaRC has invested millions of dollars over the last several years in an attempt to address the reliability issues associated with the electrical distribution system. Many components of the system are well in excess of their design life including 40-50 year old substations and 80 year old cabling. To date, the approach has been to replace in kind those components of the system which have either failed or are most at risk for failure. However, the significant transformation of the center due to new construction of the New Town buildings and consolidation/demolition of existing buildings, have required LaRC to consider a more effective and efficient way to address the persistent electrical distribution problems. In 2011, a study was commissioned to an engineering firm with expertise in the design of large electrical distribution systems. The study recommended a gradual transition from the existing 2400 volt class system to a higher 22,000 voltage class system. This multi-phase transition will allow for the elimination of the 2400 class of equipment, and greatly reduce the amount of 6600 volt class of equipment. This flattening of the electrical distribution system will reduce the number of equipment failures by eliminating the number of components, and reduce the maintenance required for the system.

Advocacy has been developed for a new CoF project to perform a gradual transition from the existing 2400 volt class system to a higher 22000 voltage class in support of Center revitalization efforts. The project calls for the construction of three new distribution loops to include 25 kV switches at the Taylor and Warner substations, 25 kV switches at the S2 and DL substations, and 25 kV switches at the Moffett and Ames substations. It is anticipated that New Town building 2, the Integrated Engineering Services Building, will be the first facility to connect to the new distribution system. The new system will be right sized consistent with the 20-year revitalization plan and will provide a robust and efficient electrical distribution system to meet the future needs of the center.

3.7 New Town Phase 3 (NT3) – Measurement Sciences Laboratory (2015 groundbreaking, funded in 2012 for design phase by agency Recapitalization Program, commitment to fund construction in 2015)

3.7.1 Project Overview

New Town building 3, the Measurement Sciences Laboratory, will be the first laboratory constructed as part of the 20-Year Revitalization Plan. The details of this project are summarized in Figure 16. This building has been approved for construction beginning in FY15 as part of the agency Recapitalization Program and Langley has received funding to develop the detailed design. This activity is currently underway. When completed, various personnel from the Engineering Directorate and Research Directorate will be housed in the Measurement Sciences Laboratory. Buildings 1202, 1220, and 1299 will be vacated and demolished as part of the project plan, thus reducing the center footprint by approximately 200,000 sq. ft. But before these buildings can be vacated, several laboratories and facilities will have to be relocated. These details are described in section 3.7.3 below. After completion, this project will save \$1.3M in yearly maintenance and utility costs and will reduce the center CRV by \$86.5M.

FY Start	Description	Justification (Demo's No Earlier Than)	Cost Savings (\$M)
2015	Lab: Measurement Sciences Lab: State-of-the-art Laser/Lidar and Electromagnetics lab; Includes sensor systems, electromagnetics and software-intensive flight systems	Relevant to all MDs; Core Campus; Demo B1299, B1202, and B1220	M+U: \$1.3 DM: \$5.0 CRV: \$86.5

Figure 16 Summary of Project Details for New Town 3

3.7.2 New Town 3 Building Construction Phase (2015 groundbreaking)

3.7.2.1 Building 3 Overview

The new Measurement Sciences Laboratory (MSL) is approved for funding in FY2015 and the design process will begin late in FY2012. Figures 17A and 17B show planning sketches of the building. This project is scheduled to be substantially completed in June 2017 and lab equipment and personnel relocations to the facility completed in Jan 2018. The building is the first laboratory in the ViTAL/New Town plan and represents a significant consolidation of Laser/Lidar and Electromagnetic technical capabilities within the Research and Engineering organizations. This building will be approximately 120,000 sq. ft. in size and located at the North end of the Center Core Area. The building will be 3 floors high, with most of the labs and offices on the first two levels and a few labs on the 3rd-floor level requiring roof top and side optical access.

Project design drivers for this project, in priority order, are:

1. Interior Environment – Optimize efficiency of laboratory operations & collaboration
2. Flexibility - Adaptable to future lab and personnel changes
3. Sustainability – Providing energy efficiency and environmental friendly features to attain a Leadership in Energy and Environmental Design (LEED) silver certification
4. Building Image and Identity – Exterior and interior elements designed to portray cutting edge research, science, and engineering

The new MSL will be a showcase design for state-of-the-art laboratory space to achieve maximum building efficiencies and use a “corridor” concept for utility distribution. The MSL will be designed for modular wet and dry bench research space and specialized space for numerous critical facilities, such as Electronics, Chemistry, Lasers, Class 100 to Class 100,000 Clean Rooms, Electromagnetic Radiation, and Instrument/Equipment High Bay Areas. The individual labs will use standard modular sizes at least 12 ft. in width to accommodate flexibility of layout and to accommodate laboratory equipment. The labs will be designed for optimum interdisciplinary interactions among branch and lab personnel. The labs will have quality work spaces through the use of humidity and temperature control, natural light, materials resistant to damage, durable finishes, and attractive furnishings. The MSL will create a space where people will want to come and work, attracting the best scientists and engineers. The lab will incorporate functions from 4 branches in the Engineering Directorate and 2 branches in the Research Directorate.



Figure 17a Schematic of New Town 3 building floor plan, *level 1*

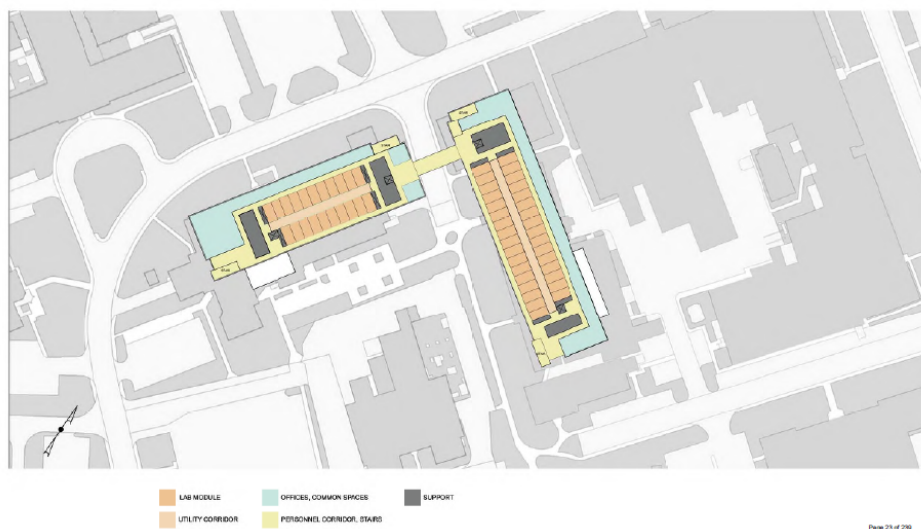


Figure 17b Schematic of New Town 3 building floor plan, level 2

3.7.2.2 Construction

The implementation plan for the NT3 Measurement Sciences Laboratory is to use a design-bid-build approach and award a construction contract through GSA using funds from NASA's recapitalization program. The final design will be completed and signed-off as architect-of-record by the New Town long term A/E (AECOM). The estimated design, construction and outfitting cost is \$93M.

3.7.2.4 Demolition

The demolition includes two buildings on the construction site: buildings B1213 and B1192 to be demolished in FY14 (also included in NT2 list) and 3 buildings whose functions are moving into the New Town 3 laboratory. These are buildings B1202, B1220, and B1299. The total area of the last group of building is 200,000 GSF.

3.7.3 Measurement Sciences Facilities Upgrades (2012, and as funds become available)

3.7.3.1 Experimental Test Range – B1299F Renovation

The Experimental Test Range (ETR), B1299F, will be renovated to increase the center's radio frequency and microwave test capability. This capability to conduct far field electromagnetic scattering and antenna experimental research in a large quiet zone volume will allow Langley to perform cutting edge measurements for years to come.

The renovation plan includes the purchase of an overhead bridge crane for the model handling area and a state of the art electronic measurement system in fiscal year 2012. Prior to the abandonment of the current Low Frequency Antenna Facility in B1299, the existing

Precision Network Analyzer based antenna measurement system and the multi axis positioner, located there will be moved to ETR. The decision was made to reuse most of the near state-of-the-art 6 year old measurement hardware, as this will significantly reduce the procurement cost of the new radar that will be purchased and installed in the new ETR. The antenna positioner can be retrofitted with a taller mast to accommodate the larger size needed in ETR. The center's planned chamber refurbishment and upgrades in fiscal year 2014 will complete the ETR renovation. This refurbishment will include replacing much of the anechoic absorbing material, the antenna feed system and a model support system. The new test capability in B1299F will replace both the Compact Range Test Facility and the Low Frequency Antenna Range currently located in B1299. ETR's measurement specifications will surpass the capabilities of both of these existing anechoic facilities in B1299.

3.7.3.2 EMI/EMC – Relocation to B1250

The existing Electromagnetic Compatibility and Interference (EMC/EMI) anechoic chamber and control room used to qualify space hardware per MIL-STD-461 and aircraft avionics per RTCA-DO-160 for electromagnetic interference housed in the rear high bay area of B1220 will be relocated to B1250 so that this test capability is co-located with the Environmental Test Laboratory where space-based science instruments and other spacecraft payloads undergo integration, processing, and flight qualification testing for compatibility to the space environment. The current EMC/EMI chamber, control room, and ancillary infrastructure will be disassembled and then rebuilt in the new B1250 location. Considerable site preparation will be required to house the EMC/EMI chamber. A study is underway to determine the engineering requirements for the re-location.

3.7.3.3 HIRF and SAFETI lab Relocation to NT3

The Systems and Airframe Failure Emulation Testing and Integration laboratory (SAFETI) and the High Intensity Radiation Facility (HIRF) located in B1220 will be moved into the new Measurement Sciences Laboratory. SAFETI is a variety of interconnected facilities and laboratories that includes an integrated avionics development test bed where proof-of-concepts experiments are conducted. The HIRF facility provides electromagnetic interference and compatibility testing including high RF upset measurements, 3 reverberation chambers, and with test capability ranging from 10 KHz to 18 GHz.

3.7.3.4 AIRSTAR and MOS to B1244

The Airborne Subscale Transport Aircraft Research (AirSTAR) flight test facility is a subscale flying test bed supported by a mobile (van) flight operations control station (MOS) for ground support. AirSTAR conducts flight research using various sub-scale models with the supporting hardware/software infrastructure, remote piloting of subscale aircraft, and autonomous vehicle flight monitoring and safety controls, flight control algorithm implementation and evaluation, data/video telemetry, data archiving, and audio communications. B1220 provides the current home base location for AirSTAR and includes a workshop for systems development and refinement. The home base for AirSTAR and the MOS will be relocated to the Langley hangar, B1244.

3.8 Data Center and High Density Office Space – B1194 (2017, in CoF advocacy)

3.8.1 Project Overview

The B1194 renovation project includes creating a new data center and high density office complex. The details of the project are summarized in Figure 18. Once completed this project will allow the co-location of numerous center personnel in buildings 1209 and 1268, and will relocate and consolidate the computer data centers currently housed in B1268. B1209 will be demolished and the vacated space in B1268 will be repurposed. While the net yearly cost savings will be modest, only about \$0.4M net, the project will significantly reduce the center footprint by 67,500 sq. ft.

A CoF advocacy package has been developed to renovate the B1194 Floyd L. Thompson Technical Library into a mixed-use facility consisting of a consolidated Center-wide data center and high-density office space. This three story structure totaling approximately 50,000 sq. ft., was originally constructed in 1942, and includes two additions executed in the 1985-90 time period. The renovation will pursue U.S. Green Building Council (USGBC) Leadership in Energy and Environmental Design (LEED) silver certification at a minimum. The preliminary renovation plan includes modifications to maximize the usable space inside the existing building shell, including extending the 2nd floor across the width of the building. A detailed internal center study is underway to support the CoF process.

In 2011 LaRC's Office of the Chief Information Officer commissioned a study of LaRC data centers focused on consolidation in support of the President-endorsed OMB mandate to improve data center efficiency and effectiveness. The OMB mandate requests that ninety percent of data centers be consolidated within one year, with the remainder to be consolidated the following year. The LaRC study identified 37 data centers (including the Science Mission Directorate's Atmospheric Science Data Center) that could be consolidated into a single location allowing for advanced monitoring systems resulting in improved efficiencies in the areas of power consumption (decreasing the center's Power Use Effectiveness from 3.0 to 1.6), cooling and humidity control requirements, reliability and capacity optimization. At present there is no single facility at LaRC with the necessary infrastructure and 18,000 sq. ft. necessary to meet the full requirements for consolidation. Building 1194 is the prime candidate for renovation in support of the OMB mandated data center consolidation effort as it is structurally sound, underutilized, and located within the Center's core campus area.

FY Start	Description	Justification (Demo's No Earlier Than)	Cost Savings (\$M)
2017	Computational/Office: rehab B1194 as a Computational Data Center and house ED/SACD; Space available to re-purpose in B1268	Relevant to all MDs; Core campus; consolidation of IT capability; energy efficient; Rehab B1194; Demo B1209 and repurpose B1268	M+U: \$0.6 DM: \$1.3 CRV: \$10.9

Figure 18 Summary of Project Details for B1194 Rehab and Data Center

3.9 New Town Phase 4 (NT4) – A. Materials/Nanotechnology Research Laboratory and B. Flight Dynamics Laboratory (2018 groundbreaking, included in agency Recapitalization Program planning, 4B contingent with Data Center CoF)

3.9.1 Project Overview

The New Town phase 4 (NT4) project plan includes two new center research and development facilities, including a new materials research laboratory for conducting nanoscale materials research and a new flight dynamics facility to replace the aging vertical spin tunnel. The project details are given in Figure 19. Once completed, 7 buildings will be demolished, thus reducing the center footprint by 147,000 sq. ft. and reducing the CRV by \$89.7M. In addition, the personnel and laboratories of the nondestructive evaluations sciences branch will be relocated in the new building and the vacated space in B1230B will available to be repurposed.

FY Start	Description	Justification (Demo's No Earlier Than)	Cost Savings (\$M)
2018	Lab: Materials/Nano Research (to include NESB and Composite Fab) and separate Flight Dynamics Research Facility (VST)	Relevant to all MDs; Core Campus; Demo B644, B645, B645A, B646, B1293C, B1267(all), and B1238(all); re-purpose B1230B	M+U: \$1.1 DM: \$5.7 CRV: \$89.7

Figure 19 Summary of Project Details for New Town 4

3.9.2 Future plans for the structures and materials assets

The new Materials/Nanotechnology Research Laboratory will be located in close proximity to the current materials and structures complex, buildings 1293, A, B, and C; and the two adjoining buildings 1148 and 1205. The plan calls for the materials labs in B1293C to be relocated in NT4 and B1293C will then be abandoned and eventually demolished. The high bay area of B1293B, originally designed for structural dynamics, and the 16 meter vacuum sphere adjoining B1293A will be retained. Likewise, many small research laboratories around the

perimeters of the high bay areas in B1148 and B1205 will be relocated into NT4. The capabilities in the Materials Processing Laboratory in B1267A and the Composite Model Shop in B1238A and B will also move into NT4 combining the RD composite materials processing and ED composite test article development facilities into an integrated capability. Buildings 1267A, 1238A and B will be abandoned and eventually demolished.

The high bay areas of B1148 and B1205, each recently renovated, will be retained. Likewise, the remote structures test facilities in B1256, Combined Loads Structures Test facility (COLTS), and B1256C, the thermal structures lab will be retained. The Landing and Impact Research (LandIR) facility, commonly referred to as the “gantry”, will be retained in the near term. However, the future work load for this facility is uncertain and the center holds a lien that requires a considerable investment to maintain an adequate corrosion prevention and control program. The center will soon have to decide on the future of LandIR. If the decision is to maintain the LandIR indefinitely, then B1297 needs to be renovated. Consideration should also be given to the future uses of B1262. One option is the relocate the personnel offices in B1297 into B1262, then B1297 can be repurposed to retain only the LandIR control room and rear laboratory space. The revitalization plan does not render a final decision on the future of the LandIR.

3.9.3 New Town 4A Overview – Material/Nanotechnology Research Laboratory

The research requirements for the Materials/Nanotechnology Laboratory include the capability to experimentally explore and validate computational simulations at multiple length scales and time scales, perform precise fabrication of material/structural components by advanced additive manufacturing methods such as 3-D printing and potentially self-assembly and other versions of molecular manufacturing, and the ability to characterize the material “state awareness” at the atomic/molecular scale and the meso- and micro- scales. The laboratory requirements will include quantum and atomistic characterization of materials, well controlled environments and advanced in-situ nondestructive evaluation methods to conduct multifunctional testing of materials/structures, vertical integration of materials development from atoms-to-structures coupled with computationally guided materials/structures/systems design capability, automated test methods including materials characterization and microscopy, and advanced manufacturing to achieve multifunctional tailored microstructures.

3.9.4 New Town 4B Overview – Flight Dynamics Laboratory

The Vertical Spin Tunnel (VST), operating in concert with the 12-Foot Low Speed tunnel co-located on the Langley East side, gives NASA and the Nation a unique experimental capability for flight dynamics research and other unique testing needs. The large subsonic test sections of these two tunnels can accommodate all manner of flight vehicles at high angles of attack, blunt bodies, and non-traditional test articles such as wind turbines and solar panel arrays. The VST is the only tunnel in the U.S. capable of conducting dynamically-scaled model tests for aircraft in spin and spin-recovery (safety of flight) conditions, which is still far beyond the capability of CFD to predict. In addition, the VST has been and will continue to be used

extensively for planetary entry, descent, and landing vehicle dynamic stability using dynamically-scaled models; static, forced oscillation, and rotary balance dynamic testing; and parachutes and other inflatable deceleration concepts. It is essential that this unique test capability be retained for future NASA missions. However, the VST and 12-foot tunnels are among the oldest tunnels at LaRC, well over 70 years old, and are also located on the Back River in a flood-prone area on the East perimeter of Langley Air Force Base, the original location of Langley Research Center prior to expanding to the West side in the 1940's. The revitalization plan has baselined a new vertical spin wind tunnel that will combine the capabilities of the VST and the 12-Foot tunnel and proposes to locate the new tunnel on the core campus adjacent to B1212 and the 14'x22' tunnel. This location allows the use of an existing flight dynamics laboratory in B1212 that supports flight dynamics testing in the 14'x22' tunnel, and thus, obviates the need for a new support building, and enables four buildings on the East side to be demolished once the new facility is fully operational.

Two options are under consideration. The first option is to design and construct a new Vertical Wind Tunnel adjacent to B1212. A single new facility can be built that will have significantly more capability than the combined capabilities of the current VST and 12-Foot to enable future NASA research and missions. The second option is to consider adapting an existing commercial Free-Fall Simulator Tunnel, normally used for sky diving practice, also to be located on the West side adjacent to B1212. Highly capable free-fall simulator tunnels have been constructed world-wide within the last fifteen years, and are approaching the test section size needed for a VST/12-Foot replacement. This option could be a considerably lower capital investment cost relative to custom-designed facility. Detailed engineering studies are underway.

In the event that the B1194 Rehab CoF project, section 3.8, is not selected for funding by the agency, the new VST proposed for New Town phase 4 will be replaced with a new data center. This would leave the existing VST and 12-Foot tunnel on the East side vulnerable to the high cost of ownership and deteriorating condition. In this event, program funding will be sought to cover the cost of the new VST. If program funding is not forthcoming, the center may exercise the option to render the VST and 12-Foot tunnels to the status of run-to-failure.

3.10 New Town Phase 5 (NT5) – Flow Physics Research Laboratory (2023 groundbreaking, in agency Recapitalization Program planning)

3.10.1 Project Overview

A new state-of-the-art flow physics research laboratory is baselined for New Town phase 5. This new laboratory will house a new mid-scale trisonic wind tunnel. The details of the project plan are summarized in Figure 20. After completion of this project, Buildings 1214 and 1251 can be vacated and demolished. The net savings to the center will be quite large, with a projected yearly savings of \$3.1M in maintenance and utilities costs. The center deferred maintenance will be reduced by \$30M and the CRV by \$325.8M. In addition, the center footprint will be reduced by 197,000 sq. ft. after demolition of B1251.

FY Start	Description	Justification (Demo's No Earlier Than)	Cost Savings (\$M)
2023	Flow Physics Research Lab Baseline includes new Trisonic Wind Tunnel	Relevant to MDs; Core campus; <i>Precursor to vacate the Eastside</i> ; Demo B1214 and B1251	M+U: \$3.1 DM: \$30.0 CRV: \$325.8

Figure 20 Summary of Project Details of New Town 5

The core of the new flow physics laboratory is a proposed trisonic wind tunnel. The objective of the trisonic tunnel is to fill the gap in the Mach number and test section size among the existing LaRC facilities. Subsonic Tunnels like the 14'-by-22' and BART provide testing capability from $M=0.05$ to 0.3 . Transonic tunnels like the TDT, NTF, and 0.3 M Cryogenic tunnel cover $M=0.2$ to about 1.2 . While the TDT and NTF are large enough, they are too costly to operate, have limited optical access into the test section, and do not possess the superior flow quality needed for a research facility. Likewise, with the closure of the UPWT supersonic tunnel, the 20" Supersonic tunnel does not provide adequate test capability to evaluate advance vehicle concepts. Several years ago, a conceptual study was conducted to provide a first iteration design and cost estimate for a versatile, easy to operate, multi-purpose research tunnel. The conceptual design called for three interchangeable test sections to provide subsonic, transonic, and supersonic test capability. A schematic of the CAD drawing of the "trisonic" tunnel from this study is shown in Figure 21.

The trisonic tunnel will be a unique facility with high quality flow characteristics designed to permit basic flow physics research and flow control concept development studies covering the Mach range of 0.1 to 1.5 with a 4'x5' test section. In addition to basic flow physics research, the trisonic tunnel will be used for screening and development of advanced aircraft configurations and space transportation vehicle concepts. The desired tunnel capabilities include:

- Autonomous, efficient operations with minimal staff (2-4 people);
- Maximum optical access to the test section to facilitate state-of-the-art nonintrusive flow field diagnostic measurements;
- Multiple test sections: subsonic, transonic, and supersonic operations each covering Semi-span, 3-D and 2-D testing capability;
- Advanced Data Acquisition System and other advanced instrumentation

It is highly desirable that the new trisonic tunnel will provide the ability to test new flexible and maneuverable concepts for new vehicle configurations. A critical requirement of the tunnel is that the potential loss of a test model should not result in the loss of tunnel from debris. In addition, the tunnel will be expected to run for long periods continuously and hence must have the ability to hold flow parameters (Mach number, Reynolds number, temperature) steady over long periods of time. It is also desirable that the tunnel will have good acoustic characteristics so that aeroacoustic research can also be conducted in the tunnel. However, an anechoic chamber surrounding the test section, coupled with the requirement that the facility efficiently operate over the entire speed range in both open and closed test section modes, might be prohibitively expensive. So a companion study will be conducted to assess the merits of splitting the trisonic

tunnel into two tunnels, one with an open test section for aeroacoustic and other low speed testing, the other tunnel having a closed test section that allows high speed testing.

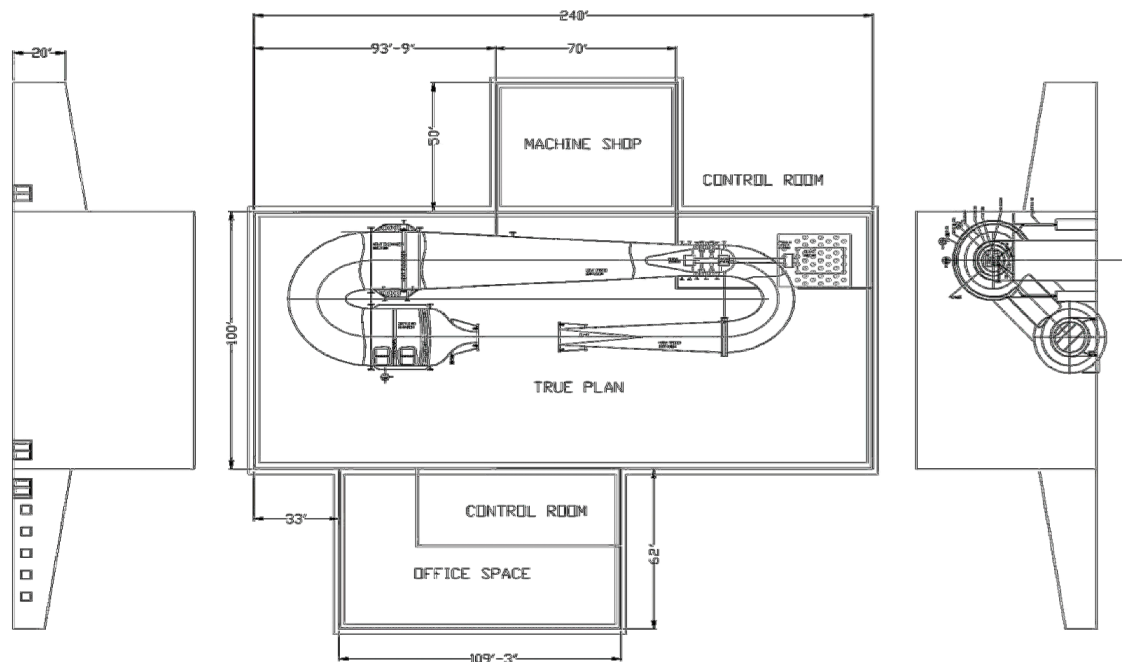


Figure 21 Schematic of proposed trisonic research wind tunnel

3.11 New Town Phase 6 (NT6) – Integrated Systems Development (2028 groundbreaking, in agency Recapitalization Program planning)

3.11.1 Project Overview

The final project phase of the revitalization plan is New Town phase 6. New Town 6 will be an integrated systems development building and will co-locate the center's engineering, environmental testing, and fabrication capabilities. The details of the project plan are summarized in Figure 22. After completion of the new building, 4 exiting building will be vacated and demolished thereby reducing the center CRV by \$77.9M and the footprint by 199,000 sq. ft. This phase will complete the consolidation of the center's engineering workforce and laboratories into the central core campus.

FY Start	Description	Justification (Demo's No Earlier Than)	Cost Savings (\$M)
2028	Lab: Integrated Systems Development Integrated Systems Development to include environmental test, fabrication and Science labs	Relevant to MDs; Core campus for ED, SACD, and SD; Demo B1225, B1232A, B1237A, and B1250 (all)	M+U: \$1.7 DM: \$3.7 CRV: \$77.9

Figure 22 Summary of Project Details for New Town 6

The new Integrated Systems Development building will consolidate the following facilities and laboratories:

- Aeronautical Systems (B1230)
- Mechanical Systems Design and Analysis (B1209)
- Integration and Environmental Test (B1220 and B1250)
- Casting (B1237A)
- Combining RD composite materials processing and ED composite test article development capabilities will maintain Langley as the Agency's Composite Center-of-Excellence;
- Fabrication Shop and Additive Manufacturing (B1232A)
- Machine Shop (B1225)

The new Integrated Systems Development building will provide the following capabilities:

- Provides the capability to design, develop, and manufacture hardware across the Technology Readiness Levels "under one roof";
- Facilitates integrated research, design, analysis, development, manufacturing, and testing activities;
- Encourages collaboration between structures and materials researchers, engineering, and fabrication personnel to develop state-of-the-art metallic and composite hardware;
- This new flexible facility (e.g., work spaces, environmental controls, utilities, structures) enables Langley to quickly respond to new and existing mission requirements;
- Expertise gained by in-house systems development, integration and testing is essential to LaRC's ability to develop viable instrument and technology demonstrator concepts, have successful mission proposals, and manage in-house or contracted projects.

A schematic of the notional facility layout is shown in Figure 23.

Facility Layout

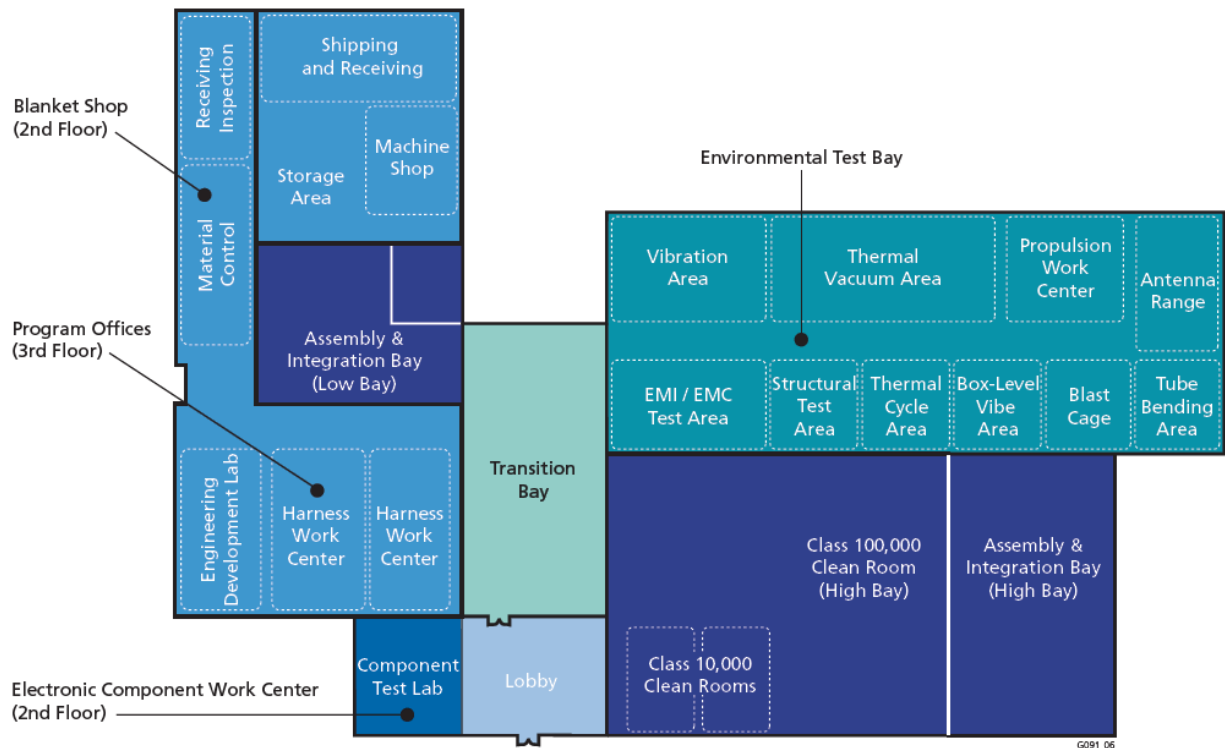


Figure 23 Facility Layout for the Integrated Systems Development Building

3.12 Center Map: current (before) and future (after Revitalization)

When completed, the 20-year Revitalization Plan will result in 6 new buildings, with 4 buildings being state-of-the-art laboratories, 12 major buildings undergoing rehab or being repurposed to improve the center's technical capability, and 24 current buildings will be rendered obsolete and demolished. Figure 24 shows the current buildings comprising the core campus (central campus on the West side) of the center; and Figure 25 shows the transformed center after completion of the revitalization plan. The center foot print will be reduced by about 1.21 M sq. ft., a 24% reduction over the current baseline, and a \$1.1 B reduction in the current replacement value (CRV), a reduction of about 33% relative to the current baseline. The resulting center will have a more centralized campus that will safely and efficiently facilitate pedestrian traffic among the building, and ample parking will be available around the perimeter of the central campus.

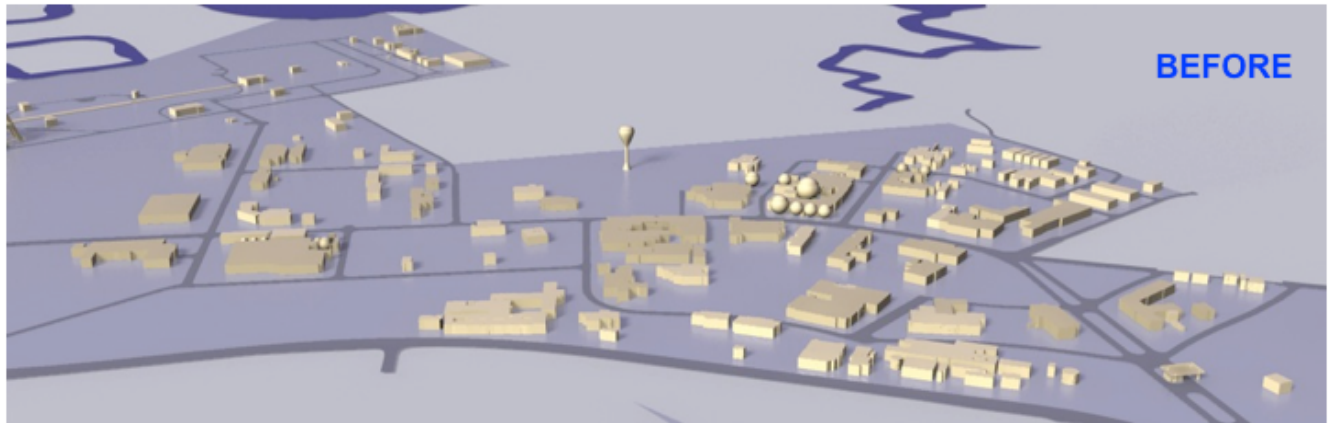


Figure 24 current center map (before revitalization)

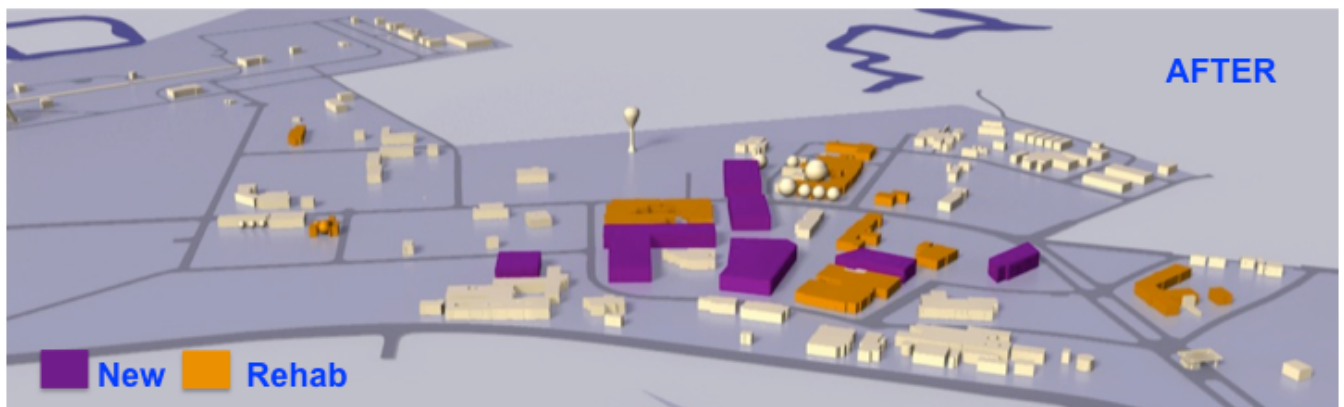


Figure 25 future center map (after revitalization)

3.13 Summary:

3.13.1 Future Plans for the LaRC Wind Tunnels

Wind Tunnels have played a prominent role in the mission of Langley throughout its rich 95 year history with the opening of the NACA's first wind tunnel laboratory at Langley Field in 1917. Indeed, the identity of Langley and the skyline of the center is often defined by its major wind tunnels. And even though many wind tunnels at Langley, and throughout the agency and nation, have been rendered obsolete and closed over the past several decades, wind tunnel development testing and experimental research remains an essential element in our center's aerodynamics, aerothermodynamics, hypersonics, and acoustics core capabilities. The center leadership is fully committed to effective stewardship of our aerosciences core competency so that LaRC remains the lead NASA center for aerodynamics R&D, as it has been throughout its rich and distinguished history.

The 20-Year Revitalization baseline plan includes 15 wind tunnels, with at least three planned in every speed regime, including the new trisonic tunnel that is baselined in the New Town 5 flow physics laboratory. (The Revitalization Program Office is also considering switching the order of New Town phases 4 and 5 to obtain the new tunnel sooner, perhaps in the 2018 quadrennial, but that decision would not be made until after we learn the future of the new data center that is being proposed as part of the building 1194 rehab in FY16 or FY17.)

LaRC Tunnels in ViTAL Plan:

The ViTAL plan includes 15 tunnels: 13 current and 2 new tunnels; plus 2 additional tunnels contingent on program funds

Current tunnels to be upgraded or repurposed (section 3.4)

4 subsonic tunnels: VST & 12' LST, 14x22, BART

3 transonic tunnels: NTF, TDT, 0.3M,

2 supersonic tunnels: 6"x10" SLDT, 20" SWT

5 hypersonic tunnels: 8FHTT, M8 VDT repurposed to replace 31" M10, 20" M6, M6 NTC repurposed to quiet flow tunnel, and AHSJTF

New Tunnels included in ViTAL baseline plan (sections 3.9 and 3.10):

1 new trisonic tunnel (with subsonic, transonic, and supersonic 4'x5' test section)

1 new flight dynamics research facility to include new improved capability to replace the VST and 12' LST

New Tunnels contingent on program funds (section 3.4):

- Multi-gas, Hypersonic Aerodynamic planetary atmosphere tunnel for EDL, plan is to repurposed CF4 tunnel
- State-of-the-art aeroacoustic wind tunnel; move or replace LSAWT or add anechoic chamber to trisonic tunnel

Proposed Tunnel closures (sections 3.4, 3.9, and 3.10):

The Revitalization plan calls for the following 8 tunnels to be closed: CF4; 12' LST; UPWT, 31" M10, and the 15" M6 in B1251; and the LSAWT, DCSTF, and CHSTF in B1221

The revitalization plan calls for retaining the 14'x22' and NTF for the duration of the 20-year plan and calls for additional investments to enhance the capability of these two tunnels. Based on the findings of an extensive market survey and the feedback provided in customer surveys, these two tunnels are being upgraded to meet the expressed needs of customers who may wish to conduct production tests. Upgrades include improvements to the flow quality, data acquisition systems, and customer work spaces. The Aeronautics Test Program (ATP), along with some Center investments, is primarily funding these upgrades.

The future of the 8'HTT is less clear and will depend on the USAF committing to test their hypersonic vehicle development engines at a funding level that will cover most of the yearly operational costs. Otherwise, the NASA mission alone may not be sufficient to sustain the tunnel.

The near-term need for the TDT continues, but the long-term need for the tunnel is uncertain. While we expect to be conducting aeroelasticity research and evaluating nontraditional airframe configurations such as the hybrid wing body and truss braced wing indefinitely, we do not expect industry to test future derivative aircraft in the TDT for flutter clearance as they have historically done. The revitalization plan calls for the TDT to close "no earlier than 2023", pending availability of the new trisonic tunnel to shift our research over to the new tunnel. The revitalization plan advocates for a new investment in the TDT to upgrade the antiquated DAS system. This DAS upgrade is currently included in the investment plans of the ATP.

Building 1251 will be vacated and will likely be demolished at some future date. The two aerothermodynamics facilities (31' M10 and 15" M6) in B1251 will be closed and new tunnels are planned for B1247 using repurposed assets on center to realize significant cost containment. The two new tunnels are the High Reynolds Number M8 tunnel (section 3.4.5) and a Multi-gas tunnel for EDL (section 3.4.6). The engineering requirements and the detailed costs estimates for these two tunnels are under development.

The center revitalization plan does indeed institutionalize major changes in how our workforce will execute some aspects of the future NASA mission which will be different than how we executed the past mission. The center leadership understands the long-term implications of these changes, but is convinced that the changes are reasonable and will not diminish our overall ability to execute the NASA mission.

3.13.2 Disposition of the Key Decision Points (see KDPs in Appendix A.)

Provided below is the complete list of KDPs developed for the 17 asset groups. See section 2.6 for a discussion of the development of the KDPs. Complete details along with various options and the initial ROM investment cost estimates are provided in Appendix A. Following the statement of each KDP, the disposition of the KDP is stated in the **blue font type in parentheticals** with a reference to the previous section(s) in chapter 3 where the resolution of the KDP has been incorporated into the revitalization plan. It should be noted that several KDPs fall outside the scope of the revitalization plan, and therefore, are not addressed within this plan.

1.0 Aerodynamics:

1.1 Project, ATP, and Reimbursable funds inadequate to operate and maintain the UPWT; advocate for funding to sustain essential supersonic research experimental capability; **(Section 3.4 and 3.10)**

1.2 Market assessment supports (or does not support) a viable external "Production Testing" reimbursable funding stream to help sustain tunnels **(section 3.13.1, upgrades to NTF, 14X22 in work; DAS upgrade to TDT in ATP plan)**

1.3 Project, ATP, and Reimbursable funds inadequate to operate and maintain the NTF and/or TDT **(section 3.13.1, NTF upgrades in work, no future decision proposed)**

1.4 Project, ATP, and Reimbursable funds inadequate to operate and maintain the Vertical Spin Tunnel, consider run-to-failure or relocate on West Side adjacent to 14x22 to reduce cost of ownership. **(Section 3.9)**

1.5 Vacate the East Side? (no future decision proposed)

2.0 Acoustics:

2.1: Close facilities in B1221 and vacate building. Must replace test capability in Low Speed Aeroacoustic Wind Tunnel (Jet Noise Lab). (Must be coordinated with KDP 4.4) **(Section 3.4)**

3.0 Aerothermodynamics:

3.1 Funds inadequate to sustain all LAL facilities and/or Center decides to vacate B1251 (Must be coordinated with KDP 1.1) **(Section 3.4)**

3.2 Funding available to sustain LAL capability and funding available for new facilities in B1247? **(Section 3.4)**

4.0 Hypersonic Airbreathing Propulsion:

4.1 Upgrade Arc-heated Scramjet: Expanded Mach number range (to M2-4) & increased dynamic pressure **(Section 3.4)**

4.2 Advocate for new state-of-the-art Supersonic Combustion Physics Laboratory; replaces current scramjet complex in B1221; **(Section 3.4)**

4.3 Scramjets in B1221 are abandon because of lack of funding and center decides to vacate B1221 (See KDP 2.1) **(Section 3.4)**

4.4 ATP, FAP/HyP, STP EDL, and DOD funding inadequate to sustain 8 Ft High Temperature Tunnel **(section 3.13.1, no decision rendered)**

5.0 Materials and Structures:

5.1 The future uses of Buildings 1297 and 1262 are tied to the future of the LandIR; renovate/rehab B1297 and/or consolidate/vacate these two buildings; make long-term decision on corrosion prevention and control program for LandIR. **(Section 3.9, no decision rendered)**

5.2 Evaluate options to relocate the Nondestructive Evaluation Sciences Labs into existing materials and structures footprint. **(Section 3.9)**

5.3 With the approval of New Town Phase 4 there are significant opportunities to create new materials and fabrication laboratories and co-locate structures and materials personnel from ED and RD. This new capability will allow further consolidation of existing laboratories and offices, and the vacated building can be re-configured or demolished. **(Section 3.9 and 3.11)**

6.0 Electromagnetics and Software-intensive Flight Systems:

6.1 Vacate Building 1299. Move Electromagnetic Properties of Materials Lab, Photonics Lab, and Smart Visual Awareness Lab to New Town #3; and re-purpose B1299F and close the Low Frequency Antenna Test Range and the Compact Test Range **(Section 3.7)**

6.2 Vacate Building 1220. Move HIRF Lab to New Town #3 or suitable alternative, consolidate EMI/EMC Lab with the Environmental Test Lab in B1250 or other suitable location, and relocate SAFETI lab in suitable alternative location **(Section 3.7)**

7.0 Systems Development:

7.1 Rehab large structures vacuum sphere (B1295) for new large space structures testing; **(funded, in work)**

7.2 Consolidate EMI/EMC Lab with the Environmental Test Lab in B1250 or other suitable location, if new high bay addition is necessary seek program funding; develop new capability for

IR Calibration (B1250), see KDP 8.3 in Sensor Systems; optimize fabrication facilities; consolidate Center's essential composites processing capability into New Town #4, allowing B1267 and B1238 to be demolished. **(Section 3.7)**

7.3 If New Town Phase 6 funds approved, consolidate multiple disciplines and associated fabrication labs and environmental test; will allow B1209, remainder of B1250 and B1225 to be vacated. **(Section 3.11)**

8.0 Sensor Systems:

8.1 In New Town Phase 3, integrate associated Laser/Lidar, Remote Sensing, and Flight Avionics Labs from B1202; **(Section 3.7)**

8.2 Develop a new Laser/Lidar Test Range (1Km), current ADLF site meets needs with building re-purposed; **(funded, in work)**

8.3: Develop a dual use Thermal-Vacuum and IR Sensor Calibration (co-locate with Environmental Test Lab in B1250 or alternate site) capability if program agrees to fund; **(Section 3.11)**

10.0 Langley Aircraft:

10.1 Continue to station Science Research Support Aircraft in-house at Langley: yes/no? **(no decision rendered)**

15.0 Measurement Sciences (flow physics, acoustics, & combustion):

15.1 Relocate the Advanced Sensing and Optical Measurements Laboratories in B1200 to B1230 after the current rehab is completed, then demolish B1200. **(Section 3.5)**

15.2 Establish an investment strategy to enable deployment of highest priority methods that are Near-Term (research development essentially complete) into the large scale tunnels with enhancements to enable rapid reduction of data to measurements of test attributes of interest. For deployment to multiple tunnels, some duplication of equipment and cross-training of facility personnel is advisable. **(not addressed in revitalization plan)**

15.3 Advocate for research funding to fully develop highest priority methods that are still under laboratory development. For Mid-term methods (development time ~3-6 years, after achieving TRL 7, consider field deployment (KDP #15.2). For Long-Term (research and development time ~6-10 years) methods, after achieving TRL 5, establish requirements for field deployment (KDP 15.2). **(not addressed in revitalization plan)**

16.0 Compute Infrastructure (computer hardware, networks, software & codes):

16.1: Should LaRC embrace cutting-edge compute capability as a key differentiator, helping to lead NASA into the virtual age? Compute can be a key differentiator for LaRC, especially in the area of algorithm development. If yes, strategic decisions must be made regarding the following factors that will be keys to success:

- Address workforce requirements to assure that the Center has the skill mix and critical mass of subject matter experts to institutionalize the KDP. **(not addressed in revitalization plan)**
- Include space for a cutting edge compute facilities in New Town 4 (or rehab to B1194)? **(Section 3.8)**
- Consolidate common compute assets, while allowing selected unique capabilities? **(Section 3.8)**

17.0 Compressor Station:

17.1 Immediately embark on repair by replacement effort, replacing the existing 3 small compressors (#1,2, and 3) with one new large compressor (8 lbs/sec, 6000 psi) reciprocating compressor and dryer within 3 years. **(Section 3.6)**

17.2 Systematically assess remaining compressors over the course of the next 15-18 years using a phased approach, the decision on each phase dictated by system capacity reassessment and budget. **(Section 3.6)**

4.0 Implementation

The ViTAL Team presented a comprehensive 20-Year Center Revitalization Plan, as documented in the first three chapters of this report, to the Langley Center Leadership Council (CLC) in the first week of March 2012. Later in March at the annual CLC retreat, the council approved the team's proposed plan and decided to move forward with implementation. Over the following two months, Langley made several visits to NASA HQ to consult with the stakeholder offices, including the Administrator, and discussed the Langley revitalization plan. These discussions reinforced the long-term strategic vision captured within the plan and confirmed the validity of the plan as being consistent with agency revitalization guidance and future funding expectations. After these consultations, the decision was made to revise the Center Master Plan to fully accommodate all the details of the 20-Year Revitalization Plan and to implement the plan through the existing functions of the Center Operations Directorate (COD), which has the Center/Agency assigned responsibility for the Center Master Plan. This approach assures the long-term institutionalization of the revitalization process.

4.1 Program Organization

A new office, The Revitalization Program Office (RPO), will be created within COD to lead the implementation of the plan. The decision was made that the office will have a lean staff and will execute the plan through the existing structure of COD. The office will be staffed by a Director, Deputy Director, and Program Analyst. The primary function of the office will be to serve as the center single point-of-contact (POC) for all aspects of the revitalization plan, which includes:

- Provide leadership within COD for all implementation planning and day-to-day program execution;
- Develop and maintain a resource-loaded project plan with a critical path schedule;
- Lead all required advocacy for individual project funding, especially when multiple fund sources may be required for project execution; coordinate with the normal yearly CoF planning process;
- Coordinate all aspects of the New Town construction projects to assure integration into the center revitalization plan;

- Assure that the center logistics and maintenance plans are administered consistent with the revitalization plan;
- Develop and execute a communications plan to assure continued stakeholder awareness and engagement in the center revitalization process;
- Together with the Office of the Director, develop and sustain a “change management” center strategy to assist the center workforce in adapting to the changes that will occur to the center.

4.2 Management Process

As the details of the implementation strategy for the revitalization plan emerge, the RPO will develop a project plan that will be executed by the existing Center functional offices. This project plan will address assumptions, dependencies, and constraints; interfaces to other related projects such as those in the Aeronautics Test Program; resource loaded schedules, milestones, metrics, and monitoring and control mechanisms; and risk management strategies. It is expected that the Center will be apprised of the Revitalization Program execution status through periodic reports to the Center Management Council, in a reporting fashion consistent with all other Center projects. Because of the complexity and time-critical nature of the New Town building construction projects, special New Town reports to the CMC may also be scheduled at the discretion of the CMC chair.

The RPO will establish an executive steering panel that will advise the Revitalization Program Director in all relevant matters. It is expected that membership on this panel will be assigned to the primary Organizations that have direct responsibility for the center’s infrastructure. These organizations include Center Operations Directorate, Research Directorate, Engineering Directorate, Science Directorate, and Research Operations Directorate. The RPO should also consider establishing a “subject matter expert” advisory panel with members from throughout the Center, to receive periodic input to the revitalization planning and execution details from the Center’s engineering, research, and technician workforce.

4.3 Budget

While the Revitalization Program will not have a dedicated budget, it will none-the-less have far-reaching responsibility to execute a yearly budget to achieve the project objectives. The RPO will be held accountable to the same financial management metrics as the other Center projects and institutional organizations. The revitalization plan investment budget has been constructed around multiple fund sources in a strategy that is consistent with the mission of each unique fund source. These fund sources include the Recapitalization Program which is administered through the agency CoF program, the regular CoF program, Center Management and Operations fund (CM&O), the Aeronautics Test Program (ATP), the Strategic Capabilities and Assets Program (SCAP), and other NASA mission-direct projects. The Recapitalization Program is/will be the fund source for the 6 New Town buildings. The regular CoF program is the fund source for building renovation and/or repurposing, and upgrades to the center’s horizontal infrastructure. Special agency funding is also available for building demolition

projects. The CM&O budget will at times make strategic investments, as funds are available, in specific facility/laboratory upgrades and future test capabilities that may fall outside the purview of current NASA projects and may also co-fund projects with sponsoring mission-direct projects. The ATP program will be the likely fund source for actions necessary to sustain and upgrade the wind tunnel facilities assigned to the ATP; and likewise, the agency SCAP program will provide sustainment and upgrade funds to the Center simulators. NASA mission-direct projects will be called on to sponsor and fund the establishment of new experimental capabilities that the Center may need to uniquely execute the work of the sponsoring project. Many specific project tasks may be co-funded by several fund sources. Because of these multiple fund sources, and the lack of a dedicated yearly budget allocation, the RPO must continually advocate for funding and seek ways to leverage all available fund sources.

4.4 Space Utilization Plan

The Revitalization Plan will require many laboratory and facility consolidation actions, thousands of personnel office moves, and extensive temporary space utilization challenges. In addition, high density office space, accommodations within the Center's core campus, and transformations in how future work will be performed will be necessary to achieve maximum flexibility and optimum utilization of all Center workspace and will require close coordination by the RPO. The RPO will assist the COD Facility Utilization Officer in determining effective near-term strategies that are consistent with the long-term 20-year plan.

4.5 Logistics – Center Storage Plan

Much of the current Center storage has evolved over years of decentralized control. While bonded storage requires controlled access space and often environmentally controlled conditions, much of the Center storage space does not require any special considerations. This has resulted in much inefficiency in space utilization. Likewise, the Center has an abundance of abandoned-in-place equipment and related facility infrastructure. As part of the Center Revitalization Plan, the RPO will work with the COD Logistics Management Branch and the government-owned equipment inventory specialists to develop and execute a strategic plan for Center wide storage.

4.6 Integrated Maintenance Plan

Maintenance is one of the largest yearly Center expenditures. Because maintenance requirements are universal, encompassing all Center assets including buildings, laboratories, facilities, experimental equipment, and the supporting utilities (horizontal Infrastructure), there are several programs with independent funding and specialized objectives. In addition, maintenance is often used as a generic term to include repair of dysfunctional office infrastructure such as plumbing and lighting (often referred to as trouble calls), replacement of aging and obsolete equipment and horizontal infrastructure before breaks occur (routine and preventative maintenance), long-term maintenance such as corrosion prevention and control, and may also include upgrades or replacement of obsolete experimental equipment. In order to assure that our yearly maintenance budgets are used as effectively as possible, and to assure that all needed maintenance does not go unaddressed, it is essential that the center develop and

execute a fully integrated center maintenance plan that is consistent with the long-term revitalization program. The RPO will be expected to play a lead role in developing and executing the integrated maintenance plan. As an executive maintenance steering council chaired by the COD Director already exists, it is expected that the RPO Director will sit on this existing council.

4.7 Environmental Management, Integration and Requirements

Environmental considerations are paramount to achieving a sustainable Center infrastructure. These considerations range from water and electrical consumption to site preparation and construction impacts to the environment. In addition, there are federal and state mandates regarding the environment that must be satisfied; and the Center is also required to have an environmental stewardship plan. It is essential that the 20-Year Revitalization Plan be implemented in an integrated fashion to assure compliance with all environmental goals and requirements.

4.8 Integrated Master Schedule

A resource-loaded program master schedule that integrates all revitalization projects will be essential for effective execution of the plan. This schedule must include all New Town construction phases; CoF renovation, repurposing and upgrade projects; all planned yearly maintenance activities, facility related projects funded by the center CM&O budget, and Center/Agency strategic investments. **It should also be noted that careful sequencing of the events in the 20-Year Revitalization Plan is essential to assure successful execution of the NASA mission.** For example, if the plan calls for a new facility to replace an existing aging facility to be followed by the decommissioning and demolition of the aging facility, it is imperative that the former precedes the later. Finally, a true critical path schedule will also need to include all key dependencies.

4.9 Status of Implementation

The Revitalization Program Office has been established. Dr. Erik S. Weiser was selected to be the Program Director, Mr. Thomas J. Quenville was selected to be the Deputy Program Director, and Ms. Michelle L. Sample was selected to be the financial analyst. The development of the implementation plan, as outlined above, is in work. The new RPO personnel are working closely with the COD functional offices to develop the implementation project plan. The New Town phase 2 is now underway, with construction of the new building in progress, and the development of the design of New Town phase 3 has been initiated. In addition, a limited amount of funding from the center's FY12 CM&O budget has been allocated to initiate several projects described in Section 3.4 and 3.7.3. These projects are viewed as essential to complete early in the revitalization process because they are precursors to later aspects of the revitalization plan. Finally, several "issue" papers have been submitted to NASA HQ as part of the annual PPBE14 budget development process. These issue papers call for accelerated funding for several of the CoF projects (sections 3.6 and 3.8).

Appendix A

Integrated Strategy for LaRC Facilities and Laboratories



Appendix A: Integrated Strategy for LaRC Facilities and Laboratories

Table of Contents

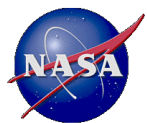
page number

I. Ground Test Facilities, Research and Development Laboratories, and Research Flight Aircraft

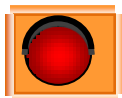
1.	Aerodynamics (subsonic, transonic, supersonic)	A3
2.	Acoustics	A10
3.	Aerothermodynamics (entry, descent, and landing)	A15
4.	Hypersonic Airbreathing Propulsion	A21
5.	Materials and Structures (includes nondestructive evaluation sciences, COLTS, and LandIR)	A26
6.	Electromagnetics and Software-Intensive Flight Systems Laboratories	A32
7.	Systems Development (Fabrication, Engineering and Environmental Testing)	A38
8.	Sensor Systems (Laser/Lidar and remote sensing)	A44
9.	Entry, Descent, and Landing (cross-referenced to Aerothermodynamics, Mat. & Struc., & Sys. Dev.)	A49
10.	Langley Aircraft	A53
11.	Flight Simulators	A57
12.	Flight Dynamics & Controls Laboratories	A61
13.	Crew Systems & Aviation Operations Laboratories	A65
14.	Science Laboratories and Atmospheric Science Data Center	A66

II. Cross-Cutting Support Physical Infrastructure and Computer Hardware/Network Infrastructure

15.	Measurement Sciences (flow physics, acoustics, and combustion)	A71
16.	Compute Infrastructure (Computer hardware, networks, software & codes)	A79
17.	Compressor Station	A83



Sources, Symbols, Definitions, Notes, Font Colors



Stop; or Standby, Mothball, Demolish



Run-to-Failure; Only Safety Repairs/Investments



Sustain Current Capability



Enhanced or New Capability

NT #

New Town Phase #



Key Decision Point (KDP) #

KDP = Conditions within the center and external factors will coalesce over time such that the future of a particular capability, equipment, facility, laboratory, or building will require a strategic decision about the role of that center asset in executing the agency mission.

Notes on Decision-framework Charts

The Technical Challenges (TC) and Test Requirements (TR) were established by disciplinary strategic planning teams comprised of SMEs from across the center. SMEs also provided the mapping of facilities to TC/TRs.

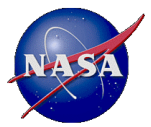
Co-dependencies connote key relationships that are essential for mission success, and typically identify cross-cutting support capability.

Black font text typically describe current capability or state scenarios leading to KDPs [note that the status quo is typically a default option for each KDP and may not be explicitly stated as such]

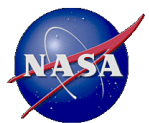
Green font text are statements of how the NASA mission is/will be executed in the future

Red font text connotes options requiring funding that must be appropriated by Center, Projects, and/or CoF

Blue font text identifies the NASA mission, work-for-others (WFO) designates reimbursable opportunities [The relevance of each capability to the NASA mission is mapped directly to the NASA strategic plan.]



1.0 Aerodynamics Facilities (subsonic, transonic, supersonic)



1.0 Aerodynamics Facilities

(ATP supported , Large Facilities)



Vertical Spin Tunnel
Dynamic Stability
& 12' tunnel , B644-646



14- by 22-Foot Subsonic Tunnel
Subsonic, Alternate Uses
B1212



National Transonic Facility
High Reynolds Number Flow
B1236



Transonic Dynamics Tunnel
Aeroelasticity & Flutter
B648



LaRC Unitary Plan
Wind Tunnel (2 legs, B1251)

Subsonic

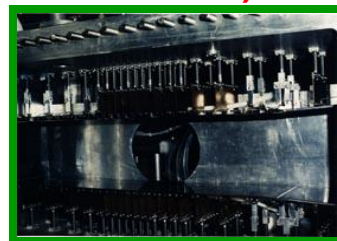
Transonic

Supersonic

(not ATP supported, Small Facilities, research tunnels)



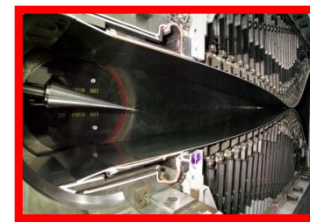
Basic Aerodynamics
Research (BART, B1214)



0.3 Meter Transonic
Cryogenic tunnel
(B1242)

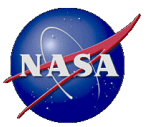


6"x10" Supersonic
Low-Disturbance
(SLDT, B1247D)



20-In Supersonic
(SWT, B1247D)

- Large Facilities (ATP) provide capability to address integrated configuration/concept testing suitable for aerodynamic/aeroacoustics research including propulsion induced effects, and code validation.
- Small Facilities (non ATP) provide complementary capability for component and unit-problem testing more suitable for exploratory research, fundamental flow physics research, and basic code development and validation activities
- Vertical spin tunnel provides stability tests of dynamically scaled aircraft and spacecraft (also see Flight Dynamics and Controls Labs)
- The 14x22 offers multiple and diverse testing capabilities that are not available in any other single facility.
- NTF provides flight Reynolds number test capability that can only be closely matched by ETW.
- TDT provides world-unique aeroelastic scaling test capabilities; also planetary atmosphere simulation
- UPWT has the highest available high pressure air and mass flow for simulating jet exhaust and plume interaction at supersonic speeds.
- Current modifications to 14x22 will extend open test section aeroacoustic testing capability beyond rotorcraft.



1.0 Aerodynamics Facilities – Mission Relevance

Strategic Goal 1: Extend and sustain human activities across the solar system.

1.2 Develop competitive opportunities for the commercial community to provide best value products and services to low Earth orbit and beyond.

Commercial Spaceflight Programs

- Commercial Cargo
- Commercial Crew

1.3 Develop an integrated architecture and capabilities for safe crewed and cargo missions beyond low Earth orbit.

Exploration System Development Programs

- Multi-Purpose Crew Vehicle
- Orion Emergency Rescue Vehicle
- Space Launch System

Strategic Goal 3: Create the innovative new space technologies for our exploration, science, and economic future.

3.1 Sponsor early-stage innovation in space technologies in order to improve the future capabilities of NASA, other government agencies, and the aerospace industry.

3.2 Infuse game-changing and crosscutting technologies throughout the Nation's space enterprise to transform the Nation's space mission capabilities.

3.3 Develop and demonstrate the critical technologies that will make NASA's exploration, science, and discovery missions more affordable and more capable.

3.4 Facilitate the transfer of NASA technology and engage in partnerships with other government agencies, industry, and international entities to generate U.S. commercial activity and other public benefits.

NASA Space Technology Roadmaps:

- TA01. Launch Propulsion Systems
- TA09. Entry, Descent, and Landing Systems
- TA11. Modeling, Simulation, Information Technology, and Processing

Strategic Goal 4: Advance aeronautics research for societal benefit.

4.1 Develop innovative solutions and advanced technologies through a balanced research portfolio to improve current and future air transportation.

Fundamental Aeronautics Program

- Fixed Wing Project
- Rotary Wing Project
- High Speed Project
- Aeronautics Sciences Project

Aviation Safety Program

- System-Wide Safety and Assurance Technologies
- Vehicle Systems Safety Technology
- Atmospheric Environment Safety Technologies

Aeronautics Test Program

4.2 Conduct systems-level research on innovative and promising aeronautics concepts and technologies to demonstrate integrated capabilities and benefits in a relevant flight and/or ground environment.

Integrated Systems Research Program

- Environmentally Responsible Aviation



1.0 Aerodynamics Facilities

Co-Dependencies:

1. Compute Infrastructure
2. Measurement Sciences
3. Compressor Station
4. Fabrication (Systems Dev)

Technical Challenges / Test Requirements:

1. Prop-Airframe Integration/Acoustics
2. Jet Interaction
3. Noise Source Identification
4. CFD code development
5. CFD data verification
6. Flow Control
7. Fluid-Structure Interaction (fixed wing and rotary)
8. Flow physics (turbulence, transition, sep flows)
9. Highly unsteady flows, including rotor aero
10. Performance (6 DOF F, M, P, T)
11. Blunt bodies (for EDL)
12. Flight dynamics (aircraft stability and control)
13. Flight dynamics (spin control and recovery)
14. Exploratory research; novel configurations

No current mission / funding

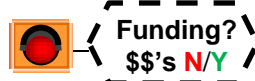
Production Testing:

14x22 [5, 10, 12]
NTF [5, 10*]
TDT [5, 7, 10*, 12]
* Requires upgrades

1. Customer Survey
2. Benchmark competition
3. Market Assessment



4. Cost of Upgrades
5. Advocate for funds



6. Aggressive marketing

Enhanced Capability also supports R & D mission

Subsonic R&D:

14x22 [1, 2, 3, 5, 6, 9, 10, 11, 12, 14]
BART [4, 5, 6, 8, 14]
12-ft Low-Speed [8, 12, 13, 14]
Vertical Spin (VST) [4, 8, 11, 12, 13, 14]

Dev'ment

14x22
VST

Mission:
HEOMD,
WFO

Research

14x22
BART
VST/12-Ft

Mission:
ARMD

Transonic R&D:

NTF [1, 4, 5, 6, 8, 10, 11, 14]
0.3-M [4, 8, 14]
TDT [4, 5, 7, 8, 9, 10, 11, 12, 14]

Dev'ment

NTF
TDT

Mission:
HEOMD,
STP, WFO

Research

NTF
0.3-M
TDT

Mission:
ARMD

Supersonic R&D

UPWT [2, 4, 5, 10, 11]
20-In SWT [4, 5, 6, 8, 14]
6"x10" SLDT [4, 5, 6, 8, 14]

Dev'ment

UPWT*

Mission:
HEOMD, STP,
WFO
*To be closed

Research

20-In SWT
6"x10"SLDT

Mission:
ARMD

VST Funds Inadequate



Partner with AFRL if VST closes

Potential to Demolish 4-6 buildings

New VST & Trisonic Tunnel?



Sustains essential R & D capability

Vacate East Side?

Funding Inadequate;
Opt A: Close NTF
Opt B: Close TDT



Sustains essential R & D capability

Establish Partnerships to test in other facilities:
[AEDC 16T, Germany ETW & DNW TWG]

Opts A or B shifts research to 0.3M



Sustains essential R & D capability

NT 5

New Trisonic Tunnel?



Sustains essential R & D capability

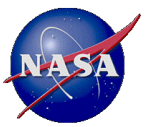
Establish Partnerships to test in other facilities:
[Ames 9x7, GRC 10x10
AEDC VK A, L/M HSWT
Boeing Polysonic]

UPWT Funds Inadequate



Sustains essential Low TRL capability

New Trisonic Tunnel?



1.0 Aerodynamics Facilities

Key Decision Points (KDP):

1.1 Project, ATP, and Reimbursable funds inadequate to operate and maintain the UPWT; advocate for funding to sustain essential supersonic research experimental capability;

Option A: upgrade test capability in existing supersonic research tunnels. ROM~\$1.65M for new nozzle plate, upgrade nozzle position control system, replace Vicker controllers, upgrade balance and data system.

Option B: Compressible Aerodynamic Research Tunnel (CART) studies have been conducted in the past decade. CART has a variable test section to support subsonic, transonic, and limited supersonic capability research with efficient two-person operations. Several CART options were identified. Small-scale, minimal capability subsonic, ROM~\$20M; Small-scale, maximum capability trisonic, ROM~\$100M (New Town #5), which also provides aeroacoustics research but with limited capability for configuration/concept studies; also investigate repurposing parts of UPWT to off-set cost of CART

1.2 Market assessment supports a viable external “Production Testing” reimbursable funding stream to help sustain tunnels [Market assessment identifies reimbursable production tests business only for 14x22, NTF, and TDT tunnels. However, upgrades to the 14x22, NTF and TDT will be required to address customer concerns about data quality, tunnel reliability, and productivity. ROM estimates for 14x22 is \$4.5M for DAS upgrade; NTF upgrades is \$1.8M (DAS improvements, flow control cal, test section access, mach control, model support, insulation); TDT upgrades ROM~ \$18M (\$4.5M DAS, \$5.3M exterior painting, \$4m oscillating vane, \$3m pressurization upgrade system, \$0.5M elevator floor, \$0.250M customer workspace)

1.3 Project, ATP, and Reimbursable funds inadequate to operate and maintain the NTF and/or TDT

Option A: close NTF; partner for high Re# development tests and integrated configuration research (EU ETW in Germany); replicating high precision drag/laminar flow and flow control tests will require modifications to Ames 11 ft; not viable to upgrade TDT to replace NTF; no other comparable large scale high Re# testing capability in the U.S.; marginal research capability exist in 0.3M cryogenic transonic tunnel; additional research capability from new trisonic option KDP 1.1, Option B

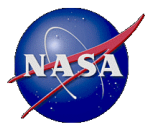
Option B: close TDT, partner for aeroelasticity development tests (Ames 11 ft, AEDC 16T, and EU DNW LLS), upgrades will be required; marginal research capability exist in 0.3M and NTF, but will have to install safety infrastructure; additional research capability from new trisonic tunnel option KDP 1.1, Option B; not viable to upgrade NTF to expand aeroelasticity research capability; closing TDT will result in lost national aeroelastic research capability unless another heavy-gas facility of suitable scale is built

1.4 Project, ATP, and Reimbursable funds inadequate to operate and maintain the Vertical Spin Tunnel, consider run-to-failure or relocate on West Side adjacent to 14x22 to reduce cost of ownership, ROM estimate from ~\$5M to relocate the VST

1.5 Vacate East Side (see next chart):

Option A: Capital investments support building a new Vertical Spin Tunnel or relocating existing VST adjacent to the 14x22; ROM estimates range from ~\$5M to relocate the VST and achieve modest upgrades to \$20M-\$30M with options on the scale of a new VST with enhanced capability.

Option B: then vacate the East Side if the Transonic Dynamics Tunnel is placed in mothball status.

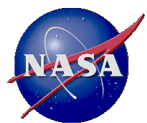


Comparison of Major Aerodynamic Wind Tunnel Facilities

NASA
And
DOD

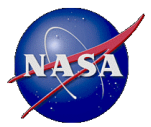
Facility (Number and Name)	Site	Cross Section	Length	Current Status (Data current as of June 2007)	Mach Number	Reynolds # (per ft x 10 ⁶)
Subsonic						
1 7' x 10' Subsonic Wind Tunnel #1	NASA Ames	7' x 10'	15'	Abandoned by NASA, Army operating	0 to 0.33	0 to 2.1
2 12' Pressure Wind Tunnel	NASA Ames	11.25' x 11'	18'	Mothballed - FY 2004	0 to 0.6	0 to 12
3 National Full-Scale Aerodynamics Complex (NFAC) 40' x 80'*	NASA Ames	39' x 79'	80'	Active - Reactivation, Air Force managing and operating	0 to 0.45	0 to 3.0
4 National Full-Scale Aerodynamics Complex (NFAC) 80' x 120'*	NASA Ames	79' x 118.3'	190'	Active - Reactivation, Air Force managing and operating	0 to 0.15	0 to 1.1
5 14' x 22' Subsonic Wind Tunnel	NASA Langley	14.5' x 21.75'	50'	Active	0 to 0.3	0 to 2.1
6 30' x 60' Wind Tunnel	NASA Langley	30' x 60'	56'	Demolished	0 to 0.15	0 to 3.2
7 20' Vertical Spin Tunnel*	NASA Langley	20' x 25'	20'	Active	0 to 0.08	0 to 0.57
8 Low Turbulence Pressure Tunnel	NASA Langley	3' x 7.5'	7.5'	Deactivated; scheduled for demolition in FY12	0.05 to 0.4	0.4 to 15
9 9' x 15' Low Speed Wind Tunnel	NASA Glenn	9' x 15'	28'	Active	0 to 0.22	0 to 1.4
10 Icing Research Tunnel*	NASA Glenn	6' x 9'	20'	Active	0.06 to 0.56	0 to 3.3
11 Anechoic Flow Facility	NSWC Carderock	8' x 8'	8.9'	Active	0 to 0.2	0 to 1.25
12 Subsonic Aerodynamic Research Lab	AFRL	7' x 10'	15'	Active	0.05 to 0.5	0 to 3.5
13 Vertical Wind Tunnel	AFRL	12'	15' high	Active	0 to 0.14	0 to 1.0
Transonic						
14 16T Propulsion Wind Tunnel (PWT)	AEDC	16' x 16'	40'	Active	0.06 to 1.6	0.4 to 6.0
15 Aerodynamic Wind Tunnel 4T	AEDC	4' x 4'	12.5'	Active	0.2 to 2.0	2.0 to 7.0
16 11' x 11' Unitary Plan Transonic Wind Tunnel*	NASA Ames	11' x 11'	22'	Active	0.4 to 1.5	0.6 to 9.6
17 National Transonic Facility (NTF)*	NASA Langley	8.2' x 8.2'	25'	Active	0.2 to 1.2	0 to 120
18 Transonic Dynamics Tunnel (TDT)*	NASA Langley	16' x 16'	30'	Active	0 to 1.2	0 to 10
19 8' x 6' Supersonic Wind Tunnel	NASA Glenn	8' x 6'	23'	Active	0.25 to 2.0	3.6 to 4.8
Supersonic						
20 16S Propulsion Wind Tunnel (PWT)	AEDC	16' x 16'	40'	Mothballed	1.5 to 4.75	0.1 to 2.4
21 Supersonic Tunnel A	AEDC	3.3' x 3.3'	7.5'	Active	1.5 to 5.5	0.3 to 9.2
22 9' x 7' Unitary Plan Supersonic Wind Tunnel	NASA Ames	9' x 7'	11'	Active	1.55 to 2.55	0.5 to 5.7
23 8' x 7' Unitary Plan Supersonic Wind Tunnel	NASA Ames	8' x 7'	16'	Abandoned	2.45 to 3.5	0.5 to 11
24 Unitary Plan Wind Tunnel Test Section #1	NASA Langley	4' x 4'	7'	Active; mothball by end of FY12	1.46 to 2.86	0.5 to 11
---- Unitary Plan Wind Tunnel Test Section #2	NASA Langley	4' x 4'	7'	Active; mothball by end of FY12	2.3 to 4.63	0.5 to 9.5
25 10' x 10' Abe Silverstein Wind Tunnel	NASA Glenn	10' x 10'	40'	Active	2.0 to 3.5	0.12 to 3.4
26 Trisonic Gas Dynamics Facility	AFRL	2' x 2'	4'	Active	0.23 to 3.0	0.5 to 7.5
Hypersonic						
27 Tunnel B	AEDC	50" dia	7.3'	Active	6.0 to 8.0	0.3 to 4.7
28 Tunnel C	AEDC	25" or 50" dia	7.3'	Active	4.0 to 10	0.2 to 8.1
29 Aerodynamic and Propulsion Test Unit (APTU)	AEDC	32" to 42" dia	16' to 20'	Undergoing upgrade	2.0 to 8.0	1.1 to 3.6
30 Tunnel 9 Simulation	AEDC White Oak	5' dia	12'	Active	8, 10, and 14	0.07 to 55.7
31 Tunnel 9 Thermal/Structural	AEDC White Oak	12" dia	24"	Active	7.0	3.5 to 15.5
32 Range/Track G	AEDC	3.3" and 8" dia	N/A	Active - Length of Range/Track G is 930 feet	0.0 to 22	Flight
33 8' High Temperature Tunnel*	NASA Langley	8' dia	12'	Active	4.0 to 7.0	0.3 to 2.2
34 31" Mach 10 Tunnel	NASA Langley	31" x 31"	34"	Active	10	0.2 to 2.2
35 20" Mach 6 Tunnel	NASA Langley	20" x 20.5"	4'	Active	6.0	0.5 to 9.0
36 20" Mach 6 CF ₄ Tunnel	NASA Langley	20" (11" dia)	6.0'	Mothball by end of FY12	6.0	0.05 to 0.75
37 15" Mach 6 High Temperature Tunnel	NASA Langley	14.5" dia	17"	Activated for lab work	6.0	0.5 to 9.0
38 Hypersonic Tunnel Facility (HTF)	NASA Plum Brook	42" dia	10'	Standby	5, 6, 7, and 8	0.97 to 2.3
39 Mach 6 High Reynolds Facility	AFRL	12" dia	20'	Mothballed (M3 8" x 8" section reactivated for lab work)	6.0	1.5 to 30
39 Total Wind Tunnels						

Gr/Fr/GtBr/Ne, European Transonic WT (ETW) = 2.0mx2.4mx9m, HiRe# & Aeroelasticity M 0.15-1.35, Re# 85 per ft x10⁶
 Germany-Dutch Wind Tunnels (DNW) TWG = 1mx1m, M 1.33-2.21, Re# 1.8 per ft x10⁶
 German Aerospace Center (DLR) VMK(vertical) = 150mmD, 230mmD, 310mmD, M 0.4-0.9 & 1.57-3.2, Re# 25 per ft x10⁶
 German Aerospace Center (DLR) TMK(trisonic) = 60cmx60cm, M 0.5-5.7, Re# 0.7-7 per ft x10⁶
 L/M HSWT = 4'x4', M 0.4-4.8, Re# 4-34 per ft x10⁶
 Boeing Polysonic = 4'x4', M 0.2-5.8, Re# 4-50 per ft x10⁶

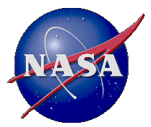


Buildings and Facilities on the LaRC East Side (LAFB)

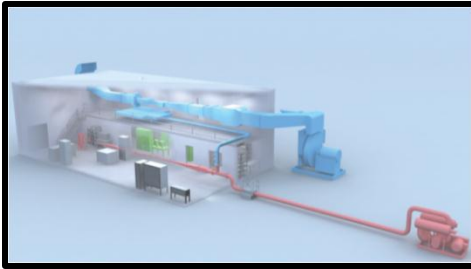




2.0 Acoustics Facilities



2.0 Acoustics Facilities



Curved Duct Test Rig & Grazing Flow Impedance Tube (B1247D)



Exterior Effects Room (B1208)



Interior Effects Room (B1208)

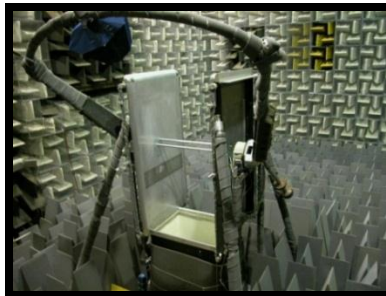


Structural Acoustics Loads & Transmission Facility (B1208)

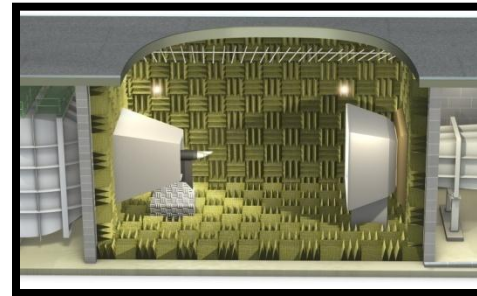
Thermal Acoustic Fatigue Apparatus (B1221, **idle**)



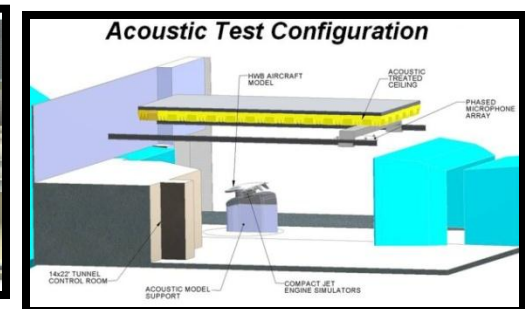
Quiet Flow Facility (B1208)



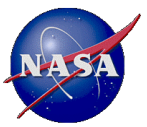
Low Speed Aeroacoustic Wind Tunnel aka JNL, (B1221) with SAJF and ADL



Phased Array Traverse System in 14x22 Tunnel



- CDTR&GFI: Unique facility for development and evaluation of acoustic liners and duct propagation prediction codes (B1247D)
- EER: Simulation and assessment of current and future revolutionary aircraft configurations using human test subjects (B1208)
- IER: Simulation of indoor sonic booms and their effect on people; development and validation of human response metrics (B1208)
- SALT: High noise qualification testing; acoustic transmission loss testing of aerospace vehicle structures (B1208)
- TAFA: High cycle fatigue of high performance aircraft and spacecraft structures under combined acoustic and thermal loads (B1221)
- QFF: Fundamental characterization of flow-surface aeroacoustics, noise reduction concepts, and model/code validation (B1208)
- LSWT: Dual stream hot jet exhaust simulator within a low-speed free jet for investigation of jet noise at realistic engine cycle conditions (B1221)
- SAJF: Single-stream, moderate temperature jet facility for fundamental experiments and development of measurement methods (B1221)
- 14x22: Characterization of acoustic source distribution and scattering of realistic propulsion-airframe models in a representative environment (B1212)



2.0 Acoustics Facilities – Mission Relevance

Strategic Goal 1: Extend and sustain human activities across the solar system.

1.1 Sustain the operation and full use of the International Space Station (ISS) and expand efforts to utilize the ISS as a National Lab for scientific, technological, diplomatic, and educational purposes and for supporting future objectives in human space exploration.

1.2 Develop competitive opportunities for the commercial community to provide best value products and services to low Earth orbit and beyond.

Commercial Spaceflight Programs (vibro-acoustics loads environment)

- Commercial Cargo
- Commercial Crew

1.3 Develop an integrated architecture and capabilities for safe crewed and cargo missions beyond low Earth orbit.

Exploration System Development Programs (vibro-acoustics loads environment)

- Multi-Purpose Crew Vehicle
- Orion Emergency Rescue Vehicle
- Space Launch System

Strategic Goal 4: Advance aeronautics research for societal benefit.

4.1 Develop innovative solutions and advanced technologies through a balanced research portfolio to improve current and future air transportation.

Fundamental Aeronautics Program

- Fixed Wing Project
- Rotary Wing Project
- High Speed Project
- Aeronautics Sciences Project

Airspace Systems Program (community noise standards)

- NextGen Concepts and Technology Development
- NextGen Systems Analysis, Integration, and Transition

Aeronautics Test Program

4.2 Conduct systems-level research on innovative and promising aeronautics concepts and technologies to demonstrate integrated capabilities and benefits in a relevant flight and/or ground environment.

Integrated Systems Research Program

- Environmentally Responsible Aviation



2.0 Acoustics Facilities

Technical Challenges / Test Requirements:

1. Flyover noise assessment of aircraft and operations
2. Cabin noise assessment of aircraft and materials
3. Evaluation/modeling of human response to sonic booms
4. Acoustic and flow field characterization of propulsion concepts
5. Performance of nozzles for uniform and mixed flow
6. Small-scale testing for concept development and validation
7. Development of acoustic measurement methods
8. High cycle fatigue due to thermal/acoustic loads
9. Transmission loss characterization and validation of new concepts
10. Vibroacoustic characterization
11. Development of acoustic liners for noise reduction
12. Characterization of liner skin friction drag and acoustic performance
13. Characterization of integrated propulsion/airframe in realistic environment
14. Validation of models and CFD/CAA codes

Co-Dependencies:

1. Compute Infrastructure
2. Compressor Station
3. Measurement Sciences

R & D: Laboratories in B1208

Exterior Effects Room [1,2,3]
Interior Effects Room [1,2,3]
Str Ac Loads & Trans Fac. [7, 9,10]
Quiet Flow Facility [6, 7, 14]
Mission: ARMD and WFOs

Recent project investments in EER & IER



Sustains essential R & D laboratories

R & D: Facilities in B1221

Thermal Ac Fatigue App (**idle**) [8, 14]
Low speed aeroac WT (JNL) [4, 5, 7, 13, 14]
Small Anechoic jet Facility [6, 7, 14]
Acoustics and Dynamics Lab (ADL)
Mission: ARMD and WFOs

Retain TAFE in **idle** & **vacate** ADL

Sustain/market JNL; retain SAJF as support for JNL

Activate TAFE if reimbursables cover costs



Retain B1221

1

Vacate B1221 yes/no?

N/Y

Retain B1221



Sustain JNL facility and supporting labs

Yes: Vacate B1221



Option 2: Transfer work in JNL to AAPL at GRC or partner with Boeing LSAF, GE C41, UK QNTF; relocate SAJF to sustain minimum research capability; abandon ADL

R&D: Specialized Capability B1247D & 14x22

Curved Duct Rig & Grazing Flow Imp Tube [11]
Phased Array Traverse Sys in 14x22 [13, 14]
Mission: ARMD and WFOs

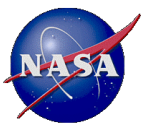
Significant recent center, agency, project investments (~ \$40M)



Sustains enhanced and unique R & D facilities; further enhancements subject to program funding

NT 5

Option 1: improved aero-acoustic capability can be added to new research trisonic tunnel and replace JNL



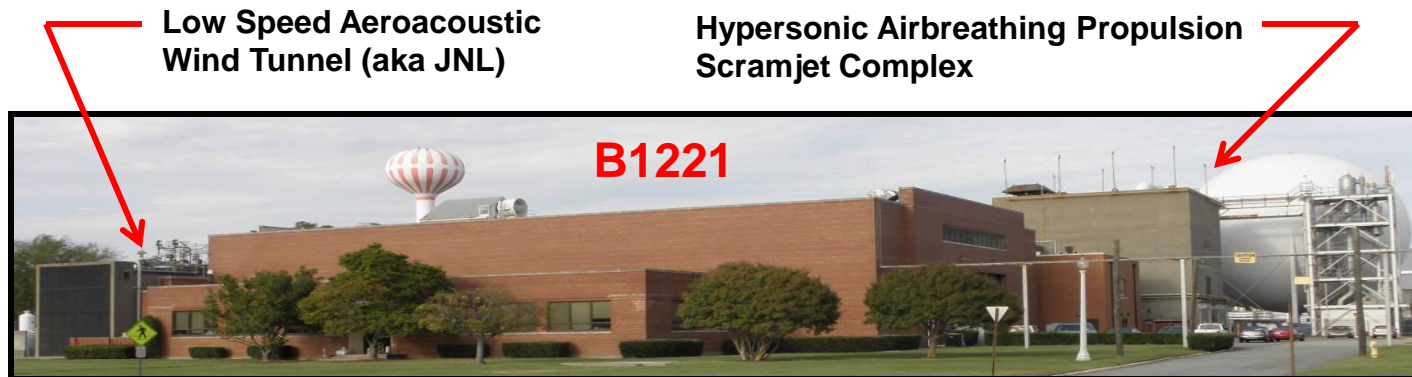
2.0 Acoustics Facilities

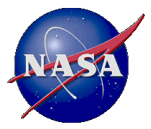
Key Decision Points (KDP):

2.1: Close facilities in B1221 and vacate building. Must replace test capability in Low Speed Aeroacoustic Wind Tunnel (Jet Noise Lab). (Must be coordinated with KDP 4.4 in Hypersonic Airbreathing Propulsion)

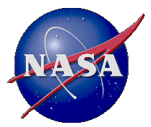
Option 1: Design state-of-the-art aeroacoustics capability in new aerodynamics research tunnel, mid-size trisonic ROM~\$100M (see KDP 1.1 in Aerodynamics); SAJF valuable as small scale, low cost, concept development capability; ADL nonessential .

Option 2: Transfer work in JNL to AAPL at GRC, requires upgrades ROM~\$2-5M in GRC AAPL to reproduce LaRC JNL test capability, or partner with Boeing LSAF, GE C41, UK QNTF; relocate SAJF to B1247, ROM~\$0.5M just to move, expand chamber and add capability options range from additional \$300K to \$2M, sustain minimum research capability SAJF; ADL is nonessential.



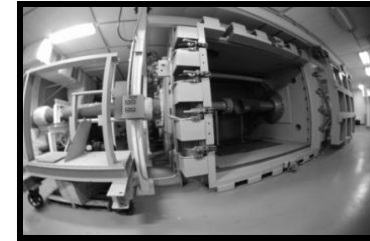
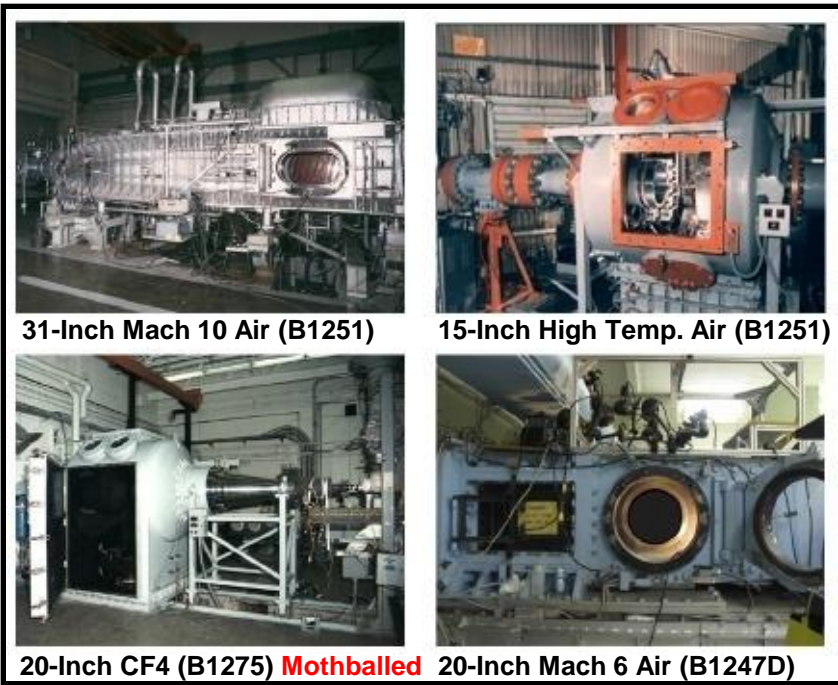


3.0 Aerothermodynamics Facilities (entry, descent, and landing)



3.0 Aerothermodynamics Facilities

ATP supported facilities:



M6 Nozzle Test Chamber (B1247D)
Idle, requires refurbishment



M8 Variable Density Tunnel (VDT, B1247D)
Idle, requires repairs/upgrades

- Conventional blow-down tunnels using perfect-gas air (except CF4 tunnel)
- High flow quality, low-enthalpy, Mach 6 and Mach 10 test conditions.
- Heat transfer, aerodynamic and flow visualization techniques
- All in regular use except 20-Inch CF4 which is in **mothball** status
- Rapid turn-around time (4-10 runs/day) allows maximum flexibility in test-planning
- Ideal capability for parametric screening, fundamental research & development, data for CFD validation.
- Unique capability for global aeroheating measurements using Langley two-color phosphor thermography method
- Utilizes Center air-handling infrastructure (compressors, vacuum-spheres, etc)
- M8 Variable Density Tunnel, 18" quiet tunnel, last run in 1999, needs repairs and upgrades, in **idle** status
- M6 Nozzle Test chamber, needs nozzle, test section, and other components; in **idle** status



3.0 Aerothermodynamics Facilities – Mission Relevance

Strategic Goal 1: Extend and sustain human activities across the solar system.

1.2 Develop competitive opportunities for the commercial community to provide best value products and services to low Earth orbit and beyond.

Commercial Spaceflight Programs

- Commercial Cargo
- Commercial Crew

1.3 Develop an integrated architecture and capabilities for safe crewed and cargo missions beyond low Earth orbit.

Exploration System Development Programs

- Multi-Purpose Crew Vehicle
- Orion Emergency Rescue Vehicle

Exploration Research and Development Programs

- Advanced Exploration Systems
- Exploration Precursor Robotic Missions
- Flagship Technology Demonstrations
- Enabling Technology Dev & Demo
- Lunar Precursor Robotic Program

Strategic Goal 3: Create the innovative new space technologies for our exploration, science, and economic future.

3.2 Infuse game-changing and crosscutting technologies throughout the Nation's space enterprise to transform the Nation's space mission capabilities.

3.3 Develop and demonstrate the critical technologies that will make NASA's exploration, science, and discovery missions more affordable and more capable.

3.4 Facilitate the transfer of NASA technology and engage in partnerships with other government agencies, industry, and international entities to generate U.S. commercial activity and other public benefits.

NASA Space Technology Roadmaps:

TA09 Entry, Descent, and Landing Systems (possible future missions):

- | | |
|----------------------------------|----------------|
| • Crewed orbital velocity return | 2015 |
| • Lunar sample return | 2017/2022/2027 |
| • Asteroid sample return | 2017/2022/2027 |
| • Venus lander | 2017/2022/2027 |
| • Mars sample return sample | 2018 |
| • ISS down-mass capability | 2018 |
| • Crewed high-vel Earth return | 2020 |
| • Mars sample return orbiter | 2022 |
| • Mars sample return surface | 2024 |
| • Crewed asteroid rendezvous | 2025 |
| • Mars network | 2029 |
| • Saturn probes | 2032 |
| • Titan aerial vehicle, landers | 2032 |
| • Crewed Mars Orbiter | 2035 |
| • Crewed Mars Surface | 2041 |
| • Icy Moon Lander | 2042 |

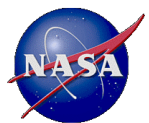
Strategic Goal 4: Advance aeronautics research for societal benefit.

4.1 Develop innovative solutions and advanced technologies through a balanced research portfolio to improve current and future air transportation.

Fundamental Aeronautics Program

- High Speed Project
- Aeronautics Sciences Project

Aeronautics Test Program



3.0 Aerothermodynamics Facilities

Co-Dependencies:

1. Compute Infrastructure
2. Measurement Sciences
3. Compressor Station
4. Fabrication

Technical Challenges / Test Requirements:

1. Aeroelastic interactions for large, inflatable / deployable aeroshells
2. RCS and thruster performance and interactions for maneuvering and control
3. Boundary-layer transition effects
4. Stage, payload, shroud interactions
5. Aerothermodynamics of complex features
6. Retro-propulsion and stagnation-point injection for deceleration, maneuvering, cooling
7. Unsteady wake-flow physics and associated wake and shear layer impingement
8. Shock-shock Interactions with inlets, wings, control surfaces, towed ballutes
9. Multi-Gas, Planetary Aerodynamics
10. High-enthalpy chemical and vibrational non-equilibrium effects during atmospheric entry
11. High Re Number Turbulent aeroheating physics
12. Aerodynamic Controls Performance

Development (primarily EDL)

31-Inch Mach 10 Air [1,2,4,6,12]
20-Inch Mach 6 Air [2,4,6,12]
20-Inch CF4 [1,2,12] mothballed

Mission: ARMD, HEOMD, STP, SMD(EDL)

Research and Development

31-Inch Mach 10 Air [1,2,3,4,5,6,7,8,12]
15-Inch High Temperature Air [5,7,8]
20-Inch Mach 6 Air [2,3,4,5,6,7,8,11,12]
20-Inch CF4 [1,2,5,7,9,10,12]

Mission: ARMD, HEOMD, STP, SMD(EDL)

Research

31-Inch Mach 10 Air [3,5,7,8]
15-Inch High Temp Air [5,7,8]
20-Inch Mach 6 Air [3,5,7,8,11]
20-Inch CF4 [5,7,9,10] mothballed

Mission: ARMD

1

Funds inadequate to sustain all LAL facilities; vacate B1251



Establish Partnerships to test in other facilities:
[AEDC VKF A/B/C, AEDC 9, CUBRC-48 & LENS-1,2,X, HyPulse, Sandia HWT]

2

Funding available for new facilities in B1247, vacate B1251



No, pursue low cost Options

YES: Replace all current LAL facilities

Option 1

Renovate M8 VDT tunnel in B1247 for High Re# [11]
a) ROM~\$2M
b) ROM~\$20M

Option 2

Relocate & repurpose CF4 Tunnel B1247, low Re# [9, 10]
ROM~\$12M

Option 3

Upgrade M6 Nozzle Test Chamber to quiet flow [3, 5, 7, 8]
ROM~\$2M

Funds inadequate to sustain all LAL facilities

Research
20-Inch Mach 6

Sustains minimum Low TRL capability

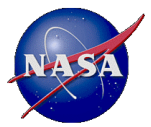
Sustains essential Low TRL capability

New SOA Facilities in B1247: provide high fidelity data for CFD development, and code V&V

High-Re# Turbulent Aeroheating [2,3,4,5,6,7,8,11,12] ROM~\$40M
Multi-Gas, Planetary Aerodynamics [1,2,3,4,5,6,7,8,9,12] ROM~\$38M
High Enthalpy Re-entry Physics [3,5,7,8,10,11] ROM~\$10M

Enhanced capability to meet all current and future research and development requirements

Research in B1247
20-Inch Mach 6 Air
M8 VDT, renovated
M6 NTC, upgraded
20-In CF4, repurposed



3.0 Aerothermodynamics Facilities



Key Decision Points (KDP):

3.1 Funds inadequate to sustain all LAL facilities and/or Center decides to vacate B1251 (See KDP 1.1 in Aerodynamics).

Option 1a: Renovate and re-open the M8 VDT in B1247D; no upgrades ROM~\$2M; use essentially as is; original capability included large Re No range, and from atmospheric pressure to 3000 psi stagnation pressure, existing 18" nozzle is adequate for most research needs. **Option 1b:** with upgrades to new High Reynolds number turbulence test capability (new nozzle, optical access, injection system, and upstream filter; ROM ~\$20M);

Option 2: Develop a multi-gas, low Reynolds number, low density test capability (repurpose CF4 tunnel assets and locate in B1247D, ROM is \$12M)

Option 3: Upgrade M6 Nozzle Test Chamber to meet new quite flow requirements for transition research (ROM is \$2M); Many components of facility already exist, however still need nozzle, test section, and other components

3.2 Funding available to sustain LAL capability and funding available for new facilities in B1247?

Options Replace all current LAL facilities with three new state-of-the-art facilities. Multiple options have been identified and range from three completely new facilities to cannibalizing existing LAL facility hardware and relocating capability in B1247. Three new facilities are: Multi-Gas, Low Re#, Low Density, Planetary Aerodynamics Tunnel ROM~\$12M-\$38M (includes option 2 CF4 conversion); High Reynolds Number Turbulent Aeroheating Facility ROM~\$40M; High Enthalpy Re# Entry Physics Facility ROM~\$4M-\$8M. New facilities would be located in B1247D. Do not have to fund all three, any combination together with options #1, #2, and #3 can also be executed.



Comparison of Major Hypersonic Test Facilities

NASA

Site	Facility	Size Inch	Mach No.	Status	Comment
NASA Ames	Arc Jet Facility			Active	Arc jet
	Hypervelocity Free Flight	1.5	25	Active	Light Gas Gun
NASA-Langley	8 Ft. High Temp	96	4-7.2	Active	Large vitiated flow facility, scramjet
	31" Mach 10	31	10	Active	Primarily S&T
	20" Mach 6	20	6	Active	Primarily S&T
	20" Mach 6 CF4	20	6	Active	Primarily S&T, Var. Gamma
	15" Mach 6 High Temp	15	6	Active	Primarily S&T, Heat Transfer
	GASL HYPULSE	6	6-10	Active	At contractor site, Real gas
	AHSTF			Active	Arc heated
	DCSTF			Active	Direct connect
NASA-Glenn	CHSTF			Active	Vitiated
	Plumbrook HTF	42	5,6,7	Mothballed	Non-Vitiated Flow, Propulsion
	PSL 4		6		Vitiated
NASA -Johnson	1'x1' Supersonic	12	6	Active	
	Arc Jet Test Facility			Active	Arc jet

Blue background
=
Minimum
required
capability

National
Partnership for
Aeronautical
Testing (NPAT)

Hypersonics
Ground Test
Infrastructure
Study (HGTIS)

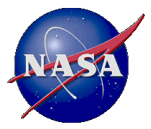
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DoD

Site	Facility	Size Inch	Mach No.	Status	Comment
AEDC	Tunnel A	40	1.5-5.5	Active	Continuous
	Tunnel B	50	6, 8	Active	Continuous
	Tunnel C	50	4, 8,10	Active	Continuous
	Tunnel 9	60	7,8,10,14	Active	Nitrogen, blowdown
	APTU	42	3,4,5,6,7	Active	Vitiated, blowdown
	Range G	-	24k ft/sec	Active	2 stage light gas gun
	ARCs (H1,H2,H3)	-		Active	Arc jet
AFRL	Cells 18,19,22			Active	vitiated, scramjet combustor develop.
	Mach 6 Hi Re	12	6	Standby	
Holloman	HSTT	-	10k ft/sec	Active	Sled track
China Lake	SNORT	-	5k ft/sec	Active	Sled track

Non-Gov

Site	Facility	Size Inch	Mach No.	Status	Comment
Sandia (DOE)	18" Hypersonic	18	5,8,14	Active	Primarily S&T
CUBRC	96" Shock Tunnel	24-96	6.5-24	Active	Primarily S&T, Real Gas
	48" Shock Tunnel	24-48	5.5-20	Active	Primarily S&T, Real Gas
	LENS I, II, X	48	5-15	Active	Aero/Optics, BMDO Invest., Real Gas
Boeing	PSWT	48	5.6	Active	
Lockheed	HSWT	48	4.8	Active	Supports Aerospace Industry
ATK GASL	Legs I-VI	Varies	8	Active	Vitiated, propulsion
Purdue	Quiet tunnel	12	6	Active	blowdown, AFOSR investment
Aero. Sys. Engr.	20" Hypersonic	20	7,11,14	Standby	
Cal Tech	T5 Piston Dr. Shock Tun	12	18	Active	Primarily S&T, Real Gas
U. Texas- Arlington	Hypersonic Shock Tun	13	6-16	Active	University Use, Real Gas
Polytechnic Univ.	36" Hypersonic Tun	36	12	Standby	University Use
	24" Hypersonic Tun	24	8	Standby	University Use



4.0 Hypersonic Airbreathing Propulsion Facilities and Laboratories

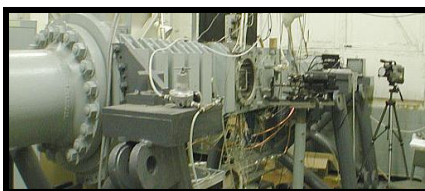


4.0 Hypersonic Airbreathing Propulsion Facilities

ATP supported Facility



8-Ft. High Temperature Tunnel
Flight Mach Enthalpy: 3 - 7



Mach 4 Blow-Down (B1221)
Low Enthalpy, Mach 4 (**idle**)

Not ATP supported Facilities and Laboratories:



Arc-Heated Scramjet (B1247D)
Flight Mach Enthalpy: 4.7- 8



HyMETS Arc-jet Facility (B1148)
TPS materials characterization



Combustion-Heated Scramjet (B1221, **idle)**
Flight Mach Enthalpy: 3.5 - 6

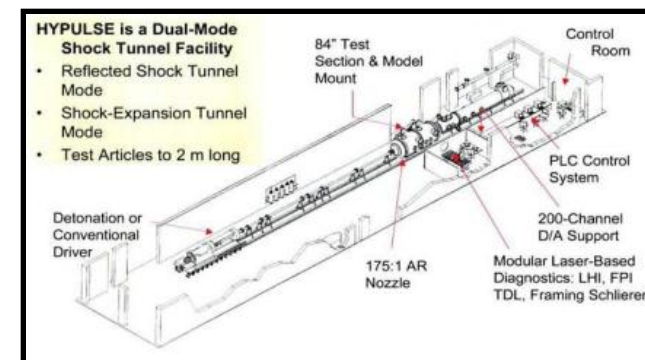


Direct-Connect Supersonic Combustion (B1221)
Flight Mach Enthalpy: 3 – 7.5

Hypersonic Airbreathing Propulsion Research Labs (B1221)

Mixing Studies Facility	Isolator Dynamics Research Lab
Non-Intrusive Diagnostics Lab	Basic Combustion Lab
Propulsion Instrumentation Shock Tube Lab (idle)	

- 8-Ft. HTT: combustion-heated blowdown tunnel, flight enthalpy for M4 to 7 with oxygen replenishment; TPS mat & structures concepts evaluation
- AHS scramjet: arc-heated, semi-freejet blowdown tunnel, M 4.7 to 8.
- CHS scramjet: combustion-heated semi-freejet blowdown tunnel, M 3.5 to 6.0.
- DCSC: combustion heated tunnel, scramjet combustors, M 4 to 7.5, using preheated hydrocarbon fuels.
- M4 Blow-Down: unheated blowdown tunnel used to screen inlets
- HyPulse (GASL): shock-expansion tunnel, studies of hypersonic airbreathing propulsion and vehicle real-gas aerothermodynamics from M 5 to 25, and simulating planetary entry at hypervelocity
- HyMETS arc-heated test chamber for TPS materials characterization



Hypersonic Pulse Facility (GASL, Long Island, NY)
Flight Mach Enthalpy: 7 – 19

[Gov Owned, NASA provides no yearly operations funding, but may provide low level funding for maintenance and special needs]



4.0 Hypersonic Airbreathing Propulsion – Mission Relevance

Strategic Goal 1: Extend and sustain human activities across the solar system.

1.3 Develop an integrated architecture and capabilities for safe crewed and cargo missions beyond low Earth orbit.

Exploration Research and Development Programs

- **Advanced Exploration Systems**
- **Flagship Technology Demonstrations**
- **Enabling Technology Dev & Demo**

Strategic Goal 3: Create the innovative new space technologies for our exploration, science, and economic future.

3.1 Sponsor early-stage innovation in space technologies in order to improve the future capabilities of NASA, other government agencies, and the aerospace industry.

3.2 Infuse game-changing and crosscutting technologies throughout the Nation's space enterprise to transform the Nation's space mission capabilities.

3.3 Develop and demonstrate the critical technologies that will make NASA's exploration, science, and discovery missions more affordable and more capable.

3.4 Facilitate the transfer of NASA technology and engage in partnerships with other government agencies, industry, and international entities to generate U.S. commercial activity and other public benefits.

NASA Space Technology Roadmaps:

- **TA01. Launch Propulsion Systems**

Strategic Goal 4: Advance aeronautics research for societal benefit.

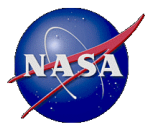
4.1 Develop innovative solutions and advanced technologies through a balanced research portfolio to improve current and future air transportation.

Fundamental Aeronautics Program

- **High Speed Project**
- **Aeronautics Sciences Project**

Aeronautics Test Program





4.0 Hypersonic Airbreathing Propulsion Facilities

Key Decision Points (KDP):

4.1 Upgrade Arc-heated Scramjet: Expanded M number range (to M2-4) & increased dynamic pressure (Nozzles, air supply system, fuel supply system, and PLC upgrade, ROM~\$2M)

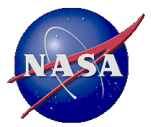
- Provides minimum required experimental capabilities to maintain HAP Core Competency and support National Programs
- Does not fully replicate existing capability of CHSTF & DCSCTF
- Best utilizes existing AHSTF infrastructure to provide required low-Mach test capability

4.2 Advocate for new state-of-the-art Supersonic Combustion Physics Laboratory; replaces current scramjet complex in B1221; 3 options identified: M7.5 H₂/Air heater ROM \$4-\$8M, M5 pebble bed/electric heater ROM \$10-\$20M, or M8 YsZ brick heater ROM \$25-\$40M

- Unique multi-investigator research laboratory that fosters internal and external collaboration, visitor-friendly and acts as a user-facility for applying state-of-the-art diagnostics to enhance understanding of physical phenomenon associated with hypersonic mixing and combustion
- Brings relevant, lab-scale, “unit-physics” experiments under one roof: supersonic reacting and non-reacting jets, mixing layers, jet-in-crossflow, cavity flows, shock-boundary layer flat plate, shock-shock interaction
- Optical access for state-of-the-art laser diagnostics: CARS, Raman/Rayleigh/LIF, PLIF, LDV, and PIV (need for simultaneous density, velocity, species measurements)

4.3 Scramjets in B1221 are abandon because of lack of funding and center decides to vacate B1221 (See KDP 2.1 in Acoustics)

4.4 ATP, FAP/HyP, STP EDL, and DOD funding inadequate to sustain 8 Ft High Temperature Tunnel



5.0 Materials and Structures Facilities and Laboratories

**(includes nondestructive evaluation
sciences, COLTS, and LandIR)**



5.0 Materials and Structures Facilities

Labs centrally located within New Town footprint



Starnes Structures and Materials Lab (B1148)



Materials Research Lab (B1205)



Light Alloy Lab (B1205)



Composites and Polymer Lab (B1293A & C)



Structural Dynamics Lab (B1293B) & 16M Vacuum Sphere

Labs remotely located outside New Town footprint



Nondestructive Evaluation Sciences Lab (B1230B)



Composites Processing Lab (B1267A)



Impact Dynamics Lab (B1262)



Thermal Structures Lab (B1256C)

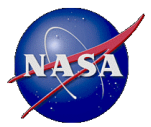


COLTS (B1256)



LandIR (B1297)

- Buildings 1148, 1205, 1293, 1267A, 1262, 1256C have large high bays with many small, enclosed, special purpose labs around periphery
- Mechanical structural testing from coupon to full-scale (1 lb to 1,000,000 lbs) (B1148)
- Material/structural testing focused on durability and damage tolerance (B1205)
- Integrated capability for alloy synthesis, characterization and testing (B1205)
- Integrated capability for polymer materials synthesis, characterization and processing (B1293C)
- Dynamic testing of spacecraft and aircraft structures, equipment and materials. (B1293A&B)
- Development of new NDE measurement technologies, autonomous systems, and integrated health management systems (B1230B)
- Dynamic response and material impact testing for determining rate-dependent material properties (B1262)
- Thermal and combined thermal-mechanical testing of structures (B1256C)
- Supports exploratory polymer fabrication research, and optimization of processing parameters (B1267A)
- R&D capable/High Readiness/Excellent Measurement Capability and DAS (all labs)
- Combined Loads Test System (COLTS): Combined axial, shear, internal pressure, and thermal loading on full-scale structures
- Landing and Impact Research facility (LandIR): drop tests under controlled horizontal and vertical velocities; land and water landing



5.0 Materials and Structures Facilities – Mission Relevance

Strategic Goal 1: Extend and sustain human activities across the solar system.

1.1 Sustain the operation and full use of the International Space Station (ISS) and expand efforts to utilize the ISS as a National Lab for scientific, technological, diplomatic, and educational purposes and for supporting future objectives in human space exploration.

- **MISSE-X Projects**

1.2 Develop competitive opportunities for the commercial community to provide best value products and services to low Earth orbit and beyond.

- **Commercial Spaceflight Programs**

- **Commercial Cargo**
- **Commercial Crew**

1.3 Develop an integrated architecture and capabilities for safe crewed and cargo missions beyond low Earth orbit.

- **Exploration System Development Programs**

- **Multi-Purpose Crew Vehicle**
- **Orion Emergency Rescue Vehicle**
- **Space Launch System**

- **Exploration Research and Development Programs**

- **Exploration Precursor Robotic Missions**
- **Flagship Technology Demonstrations**
- **Human Research Program (radiation physics)**
- **Enabling Technology Dev & Demo**
- **Lunar Precursor Robotic Program**

Strategic Goal 2: Expand scientific understanding of the Earth and the universe in which we live.

2.2 Understand the Sun and its interactions with Earth and the solar system.

- **Heliophysics Programs**

- **Near Earth networks**
- **New Millennium**

2.3 Ascertain the content, origin, and evolution of the solar system and the potential for life elsewhere.

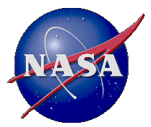
- **Planetary Science Programs**

- **Discovery**
- **Mars Exploration**
- **New Frontiers**

2.4 Discover how the universe works, explore how it began and evolved, and search for Earth-like planets.

- **Astrophysics Programs**

- **Astrophysics Explorer**
- **Cosmic Origins Exoplanet Exploration**



5.0 Materials and Structures Facilities – Mission Relevance

Strategic Goal 3: Create the innovative new space technologies for our exploration, science, and economic future.

- 3.1 Sponsor early-stage innovation in space technologies in order to improve the future capabilities of NASA, other government agencies, and the aerospace industry.
- 3.2 Infuse game-changing and crosscutting technologies throughout the Nation's space enterprise to transform the Nation's space mission capabilities.
- 3.3 Develop and demonstrate the critical technologies that will make NASA's exploration, science, and discovery missions more affordable and more capable.
- 3.4 Facilitate the transfer of NASA technology and engage in partnerships with other government agencies, industry, and international entities to generate U.S. commercial activity and other public benefits.

NASA Space Technology Roadmaps:

- **TA09. Entry, Descent, and Landing Systems**
- **TA10. Nanotechnology**
- **TA11. Modeling, Simulation, Information Technology, and Processing**
- **TA12. Materials, Structures, Mechanical Systems, and Manufacturing**

Strategic Goal 4: Advance aeronautics research for societal benefit.

- 4.1 Develop innovative solutions and advanced technologies through a balanced research portfolio to improve current and future air transportation.

Fundamental Aeronautics Program

- **Fixed Wing Project**
- **Rotary Wing Project**
- **High Speed Project**
- **Aeronautics Sciences Project**

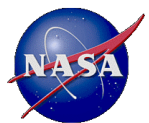
Aviation Safety Program

- **System-Wide Safety and Assurance Technologies**
- **Vehicle Systems Safety Technology**
- **Atmospheric Environment Safety Technologies**

- 4.2 Conduct systems-level research on innovative and promising aeronautics concepts and technologies to demonstrate integrated capabilities and benefits in a relevant flight and/or ground environment.

Integrated Systems Research Program

- **Environmentally Responsible Aviation**



5.0 Materials and Structures Facilities

Co-Dependencies:

1. Compute Infrastructure
2. Fabrication

Technical Challenges / Test Requirements:

1. Dramatic mass savings from emerging materials
2. Design multifunctional systems to optimized properties by computational models
3. Manipulate matter at atomic/molecular level
4. Enable bio-inspired materials development
5. Dramatically reduce the time/cost for new materials, design, development and certification
6. Advanced testing/characterization integrated with computational modeling and simulation
7. Ultra-high reliability and autonomous sustainment
8. Structural health assessment for material state awareness and vehicle/system level prognosis
9. Design structural materials for durability and inspection

Dev Tests (High Bay Areas):

St Str & Mat (B1148)
Mat Res Lab (B1205)
Str Dyn Lab (B1293B)
16M Vacuum Sphere (1293)
Impact Dyn Lab (B1262)
Comp proc Lab (B1267A)
Thermal Str Lab (B1256C)
COLTS (B1256)
LandIR (B1297)

Research and Development:

St Str & Mat Lab [1, 2, 5, 6, 7, 8, 9]
Materials Res Lab [1, 2, 5, 6, 7, 8, 9]
Light Alloy Lab [1, 2, 3, 6]
Comp & polymer Lab [1, 2, 3, 4, 6]
Str Dynamics Lab [2, 5, 6, 8]
Nondestructive Eval Sc Lab [8, 9]
Comp processing Lab [3, 5, 6]
Impact Dynamics Lab [5, 6, 7]
Thermal Structures Lab [5, 6, 9]
COLTS [5, 6]
LandIR [6]

Mission: ARMD, HEOMD, STP, SMD, WFO

Research (laboratories):

St Str & Mat Labs
Materials Res Labs
Light Alloy Labs
Comp & polymer Labs
Nond Eval Sc Labs
Comp processing Labs
Impact Dynamics Lab

Sustains
Essential
Low TRL
capability

New Capabilities:

Large Space Structures
Deployment (vacuum sph
B1295; upgrades required)

1

2

3

Renovate/Consolidate/Vacate:

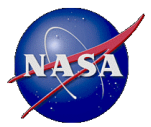
St Str & Mat (combine Imp Dyn Lab)
Mat Res Lab (combine NDES Labs)
Str Dyn Lab (reclaim space)
Comp Proc Lab (combine Fab, EBF3?)
LandIR control Rm & office (renovate)
Impact Dynamics Lab (vacate B1262)
Nond Eval Sc Labs (vacate B1230B)

New Lab, Integrated Capabilities:

Nanostructured Materials
Atomistic Characterization Lab
Bio-inspired materials
Comp & Polymers Labs
Rapid manufacturing, 3-D printing
Integrated ED/RD labs/offices

NT 4

New capabilities enables future research
in quantum/nano materials/physics and
integrates pathfinder fabrication methods



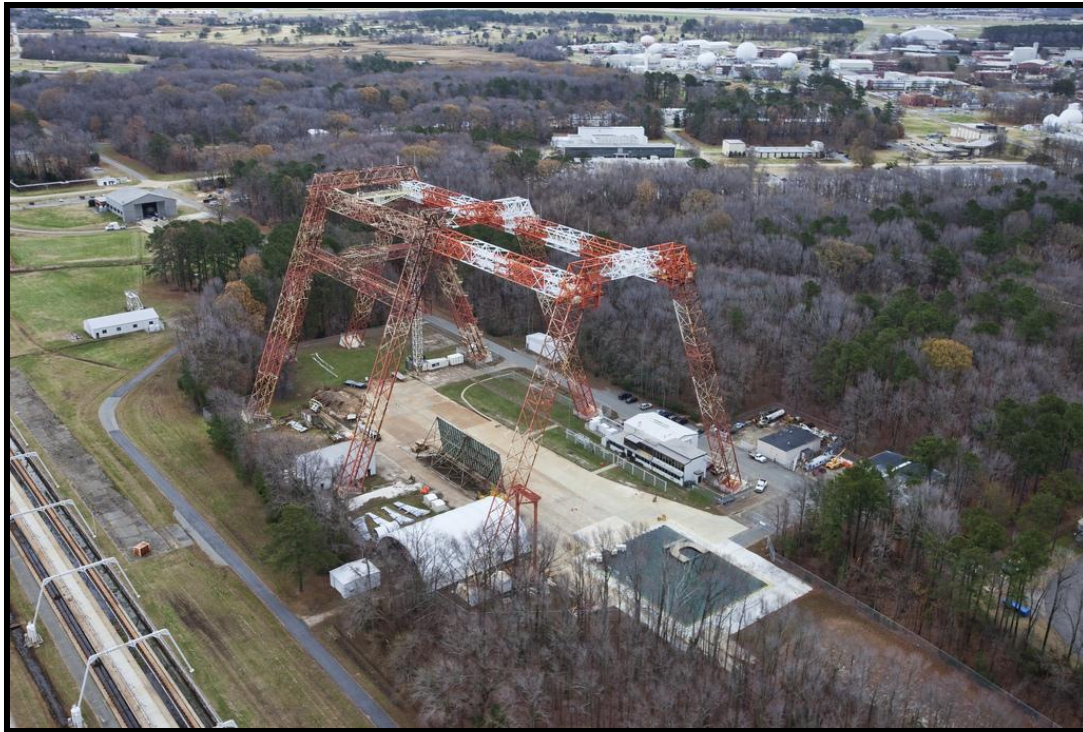
5.0 Materials and Structures Facilities

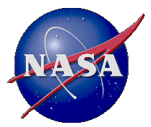
Key Decision Points (KDP):

5.1 The future uses of Buildings 1297 and 1262 are tied to the future of the LandIR; renovate/rehab B1297 and/or consolidate/vacate these two buildings; make long-term decision on corrosion prevention and control program for LandIR.

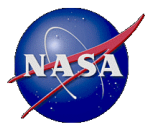
5.2 Evaluate options to relocate the Nondestructive Evaluation Sciences Labs into existing materials and structures footprint.

5.3 With the approval of New Town Phase 4 there are significant opportunities to create new materials and fabrication laboratories and co-locate structures and materials personnel from ED and RD. This new capability will allow further consolidation of existing laboratories and offices, and the vacated building can be re-configured or demolished.





6.0 Electromagnetics and Software-Intensive Flight Systems Laboratories



6.0 Electromagnetics and Software-Intensive Flight Systems Labs



**Systems & Airframe Failure
Emulation Testing &
Integration (SAFETI) Lab,
B1220**



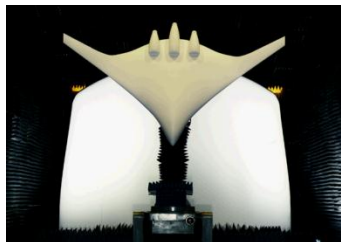
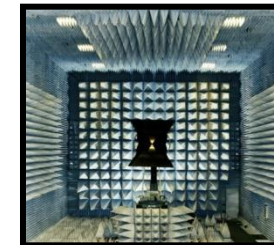
**High Intensity Radiation
Facility (HIRF, B1220)**



**AirSTAR and Mobile Operations
Station (MOS), at B1220**



**Electromagnetic Prop Low Frequency Antenna
Test Facility, B1299**



**Compact Test Range,
B1299**



**Experimental Test
Range, B1299F**



Photonics (laser) Lab, B1299

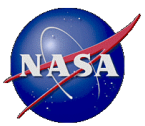


**Smart Visual Awareness
Lab, B1299**



**Mobile Radar Van,
at B1299**

- SAFETI: variety of interconnected facilities and labs, integrated avionics development testbed and proof-of-concept experiments
- HIRF: electromagnetic interference / compatibility, high RF field upset measurements, 3 reverberation chambers, 10 KHz – 18 GHz
- AirSTAR & MOS: flight research using various sub-scale models, hardware/software infrastructure, remote pilot of subscale aircraft, flight control algorithm impl/eval, data/video telemetry, data archiving, audio comm
- Electromagnetic Properties of Materials Lab: 1–18 GHz waveguide sample holder, Ka Band 26.5-40 GHz & W band 75-90 GHz
- Low Frequency Antenna Test Facility: tapered far field anechoic range, 200 MHz – 18 GHz, Ka Band 26.5 GHz to 40 GHz
- Compact Range Test Facility: electromagnetic scattering and antenna performance, anechoic chamber, 500 MHz – 40 GHz
- Experimental Test Range: microwave compact range, 300MHz-18 GHz, 13'x13' test section, not in operation as originally designed
- Photonics Lab: advanced photonics and Lidar fabrication and testing, High Spectral Resolution Laser (HSRL) development
- Smart Visual Awareness Lab: optical & IR enhanced imaging, patented Retinex software, real time DSP processing for flight deck vision
- Mobile Radar Van: 34' vehicle for remote radar research at airports and specialized locations with ADS-B and kinetic weather events



6.0 Electromagnetics and Software-Intensive Flight Systems Labs -- -- Mission Relevance

Strategic Goal 1: Extend and sustain human activities across the solar system.

1.3 Develop an integrated architecture and capabilities for safe crewed and cargo missions beyond low Earth orbit.

Exploration System Development Programs

- Multi-Purpose Crew Vehicle
- Exploration Research and Development Programs
- Enabling Technology Dev & Demo

Strategic Goal 2: Expand scientific understanding of the Earth and the universe in which we live.

2.1 Advance Earth system science to meet the challenges of climate and environmental change.

Earth Science Programs

- Earth Science Multi-Mission Operations
- Earth System Science Pathfinder
- Earth Systematic Missions

Future Earth Science missions include:

- **CLARREO** - Climate Absolute Radiance and Refractivity Observatory
- **ASCENDS** – Active Sensing of CO₂ Emissions over Nights, Days, & Seasons
- **GEO-Cape** - Geostationary Coastal and Air Pollution Events mission
- **3-D WINDS** Dimensional Tropospheric Winds from Space-based Lidar
- **CERES** – clouds and the Earth's Radiant Energy System
- **SAGE** – stratospheric aerosol and gas experiment

Strategic Goal 3: Create the innovative new space technologies for our exploration, science, and economic future.

3.1 Sponsor early-stage innovation in space technologies in order to improve the future capabilities of NASA, other government agencies, and the aerospace industry.

3.2 Infuse game-changing and crosscutting technologies throughout the Nation's space enterprise to transform the Nation's space mission capabilities.

3.3 Develop and demonstrate the critical technologies that will make NASA's exploration, science, and discovery missions more affordable and more capable.

3.4 Facilitate the transfer of NASA technology and engage in partnerships with other government agencies, industry, and international entities to generate U.S. commercial activity and other public benefits.

NASA Space Technology Roadmaps:

- **TA02. In-Space Propulsion Technologies**
- **TA04. Robotics, TeleRobotics, and Autonomous Systems**
- **TA08. Science Instruments, Observatories, and Sensor Systems**
- **TA09. Entry, Descent, and Landing Systems**
- **TA11. Modeling, Simulation, Information Technology, and Processing**



6.0 Electromagnetics and Software-Intensive Flight Systems Labs -- --Mission Relevance

Strategic Goal 4: Advance aeronautics research for societal benefit.

4.1 Develop innovative solutions and advanced technologies through a balanced research portfolio to improve current and future air transportation.

Airspace Systems Program

- NextGen Concepts and Technology Development
- NextGen Systems Analysis, Integration, and Transition

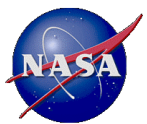
Aviation Safety Program

- System-Wide Safety and Assurance Technologies
- Vehicle Systems Safety Technology
- Atmospheric Environment Safety Technologies

4.2 Conduct systems-level research on innovative and promising aeronautics concepts and technologies to demonstrate integrated capabilities and benefits in a relevant flight and/or ground environment.

Integrated Systems Research Program

- Unmanned Aircraft Systems in the National Airspace System



6.0 Electromagnetics and Software-Intensive Flight Systems Labs

Co-Dependencies:

1. Compute Infrastructure

Technical Challenges / Test Requirements:

1. Designer materials/chemistry & metamaterials
2. Autonomous scene (pattern) recognition
3. All-weather flight operations (by remote sensing)
4. Wireless everything, sensor networks and swarms
5. High power electromagnetics (beaming, levitation, in-space propulsion)
6. Robotic/Autonomous vehicles (machine intelligence)
7. Distributed air traffic management
8. Design integrity / formal methods
9. System safety assurance (software-intensive systems)
10. Operational integrity (architectural concepts, verified solutions, system requirements)
11. Experimental validation (avionics IVHM, UAS platforms)

R and D in B1220:

SAFETI Lab
HIRF Facility
AirSTAR & MOS

Vacate B1220? **2**

N/Y

No



Sustain
current
capability

Yes



Consolidate / relocate
SAFETI Lab (options
B1268, B1230, or NT #3?)

Relocate AirSTAR and
MOS to hangar



Close, relocate, or rebuild
around HIRF Facility
(ROM~\$M?)

Research and Development:

SAFETI Lab [9, 10, 11]
HIRF Facility [4, 5, 7, 9]
AirSTAR & MOS [6, 7, 8, 9, 10, 11]
Elect Prop Mat [1, 4]
Low Freq Antenna Test [?]
Compact Test Range [4, 5, 11]
Exp Test Range [5, 6, 11]
Photonics (laser) Lab [3, 6]
Smart Visual Aw Lab [2, 3]
Mobile Radar Van [6, 7, 11]

Mission: ARMD, HEOMD, SMD, STP

NT 3

R and D in B1299&F:

Elect Prop Mat
Low Freq Antenna Test
Compact Test Range
Exp Test Range
Photonics (laser) Lab
Smart Visual Aw Lab
Mobile Radar Van

1 Vacate B1299?

N/Y

No



Building age
and condition
will eventually
require rehab

Yes or No

Yes



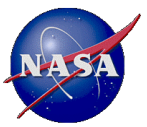
Repurpose Exp Test Range,
B1299F (ROM~<\$4M),
close LFAntenna and Compact
Test Ranges



Consolidate Elect
prop Mat with
materials labs in
B1293 or NT 3/4



Move Photonics
and SmVisAw
Labs in NT 3/4

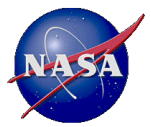


6.0 Electromagnetics and Software-Intensive Flight Systems Labs

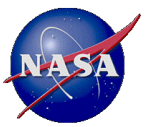
Key Decision Points (KDP):

6.1 Vacate Building 1299. Move Electromagnetic Properties of Materials Lab, Photonics Lab, and Smart Visual Awareness Lab to New Town #3; and re-purpose B1299F and close the Low Frequency Antenna Test Range and the Compact Test Range ROM~<\$4M

6.2 Vacate Building 1220. Move HIRF Lab to New Town #3 or suitable alternative, consolidate EMI/EMC Lab with the Environmental Test Lab in B1250 or other suitable location, and relocate SAFETI lab in suitable alternative location



7.0 Systems Development (Fabrication, Engineering and Environmental Testing)



7.0 Systems Development Facilities

Fabrication Facilities



**Composite Model
Development Lab
B1238B**



**Advanced Machining
Development Lab
B1225 & B1245**



**Flt Test Article
Development &
Integr. Lab 1232A**



**Microelectronics
Development Lab
B1238A**



**Investment Casting
Development Lab
B1237A**

Engineering and Environmental Test



**Flight Electronics
& Software B1202**



**EMI/EMC
Test Facilities B1220**



**Vibration Test
Labs B1250**

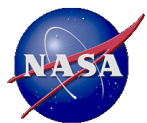


**Thermal-Vacuum
B1250**



**Instr Processing
Cleanroom B1250**

- Buildings 1238, 1238B, 1232A, 1225, 1250, 1202 high bays for systems integration, fabrication, environmental test and flight avionics labs
- Vibration testing of aerospace components, subsystems, and small payloads; sine sweep (5 to 2000 Hz), random (20 to 2000 Hz) (B1250)
- Mechanisms Development Lab, liquid-Helium thermal-vacuum chamber, temp range 20K to 300K and press from atm to 1×10^{-6} torr (B1202)
- 8' x 15'; 6' X 6'; 5X5; clean thermal-vacuum chambers can achieve a temperature of -310°F and uses quarts lamps for heating which can heat a test article to approximately 220°F; test pressures from atmosphere to 1×10^{-6} torr (B1250)
- 40' X 40' X 16' Class 1000K Cleanroom for Instrument and Space flight hardware processing (B1250); 1000K Cleanroom (B1202, B1250)
- Flight Electronics Labs, development, test and integration for flight hardware (B1202)
- Electromagnetic Compatibility Testing; Provide testing per MIL-STD-461 for spaceflight hdw and RTCA-DO-160 for aeronautics hdw (B1220)
- Pyrotechnics and explosive storage and processing for flight systems and ground-based testing (B1159 and B1158, not pictured above)
- Composite test articles dev, test article instrumentation, autoclave processing, CNC for composites (B1238B)
- Materials castings (ceramics, metals and resins), composite coupon machining and additive manufacturing. (B1237A)
- Sensor/actuation development, laser ablation applications, electronics fabrication and scanning electron microscope. (B1238A)
- Welding, large test article integration, advanced processing EBF and large metallic rolling (currently in standby) (B1232 and 1244A)
- Metallic machining, CNC machining, turning and electro-discharge and general and precision machining (B1225 and B1245, metal shed)



7.0 Systems Development -- Mission Relevance

Strategic Goal 1: Extend and sustain human activities across the solar system.

1.1 Sustain the operation and full use of the International Space Station (ISS) and expand efforts to utilize the ISS as a National Lab for scientific, technological, diplomatic, and educational purposes and for supporting future objectives in human space exploration.

1.2 Develop competitive opportunities for the commercial community to provide best value products and services to low Earth orbit and beyond.

Commercial Spaceflight Programs

- **Commercial Cargo**
- **Commercial Crew**

1.3 Develop an integrated architecture and capabilities for safe crewed and cargo missions beyond low Earth orbit.

Exploration System Development Programs

- **Multi-Purpose Crew Vehicle**
- **Orion Emergency Rescue Vehicle**
- **Space Launch System**

Exploration Research and Development Programs

- **Advanced Exploration Systems**
- **Exploration Precursor Robotic Missions**
- **Flagship Technology Demonstrations**
- **Enabling Technology Dev & Demo**
- **Lunar Precursor Robotic Program**

Strategic Goal 2: Expand scientific understanding of the Earth and the universe in which we live.

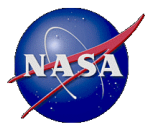
2.1 Advance Earth system science to meet the challenges of climate and environmental change.

Earth Science Programs

- **Earth Science Multi-Mission Operations**
- **Earth Science Technology**
- **Earth System Science Pathfinder**
- **Earth Systematic Missions**

Future Earth Science missions include:

- **CLARREO** - Climate Absolute Radiance and Refractivity Observatory
- **ASCENDS** – Active Sensing of CO₂ Emissions over Nights, Days, & Seasons
- **GEO-Cape** - Geostationary Coastal and Air Pollution Events mission
- **3-D WINDS** Dimensional Tropospheric Winds from Space-based Lidar
- **CERES** – clouds and the Earth's Radiant Energy System
- **SAGE** – stratospheric aerosol and gas experiment



7.0 Systems Development – Mission Relevance

Strategic Goal 2: Expand scientific understanding of the Earth and the universe in which we live.

2.2 Understand the Sun and its interactions with Earth and the solar system.

Heliophysics Programs

- Heliophysics Explorer
- Living with a Star
- Near Earth networks
- New Millennium
- Solar Terrestrial probes

2.3 Ascertain the content, origin, and evolution of the solar system and the potential for life elsewhere.

Planetary Science Programs

- Discovery
- Mars Exploration
- New Frontiers
- Outer Planets

2.4 Discover how the universe works, explore how it began and evolved, and search for Earth-like planets.

Astrophysics Programs

- Astrophysics Explorer
- Cosmic Origins Exoplanet Exploration

Strategic Goal 3: Create the innovative new space technologies for our exploration, science, and economic future.

3.1 Sponsor early-stage innovation in space technologies in order to improve the future capabilities of NASA, other government agencies, and the aerospace industry.

3.2 Infuse game-changing and crosscutting technologies throughout the Nation's space enterprise to transform the Nation's space mission capabilities.

3.3 Develop and demonstrate the critical technologies that will make NASA's exploration, science, and discovery missions more affordable and more capable.

3.4 Facilitate the transfer of NASA technology and engage in partnerships with other government agencies, industry, and international entities to generate U.S. commercial activity and other public benefits.

NASA Space Technology Roadmaps:

- TA04. Robotics, TeleRobotics, and Autonomous Systems
- TA05. Communication and Navigation
- TA08. Science Instruments, Observatories, and Sensor Systems
- TA09. Entry, Descent, and Landing Systems
- TA12. Materials, Structures, Mechanical Systems, and Manufacturing
- TA14. Thermal Management Systems

Strategic Goal 4: Advance aeronautics research for societal benefit.

4.1 Develop innovative solutions and advanced technologies through a balanced research portfolio to improve current and future air transportation.

Aeronautics Test Program

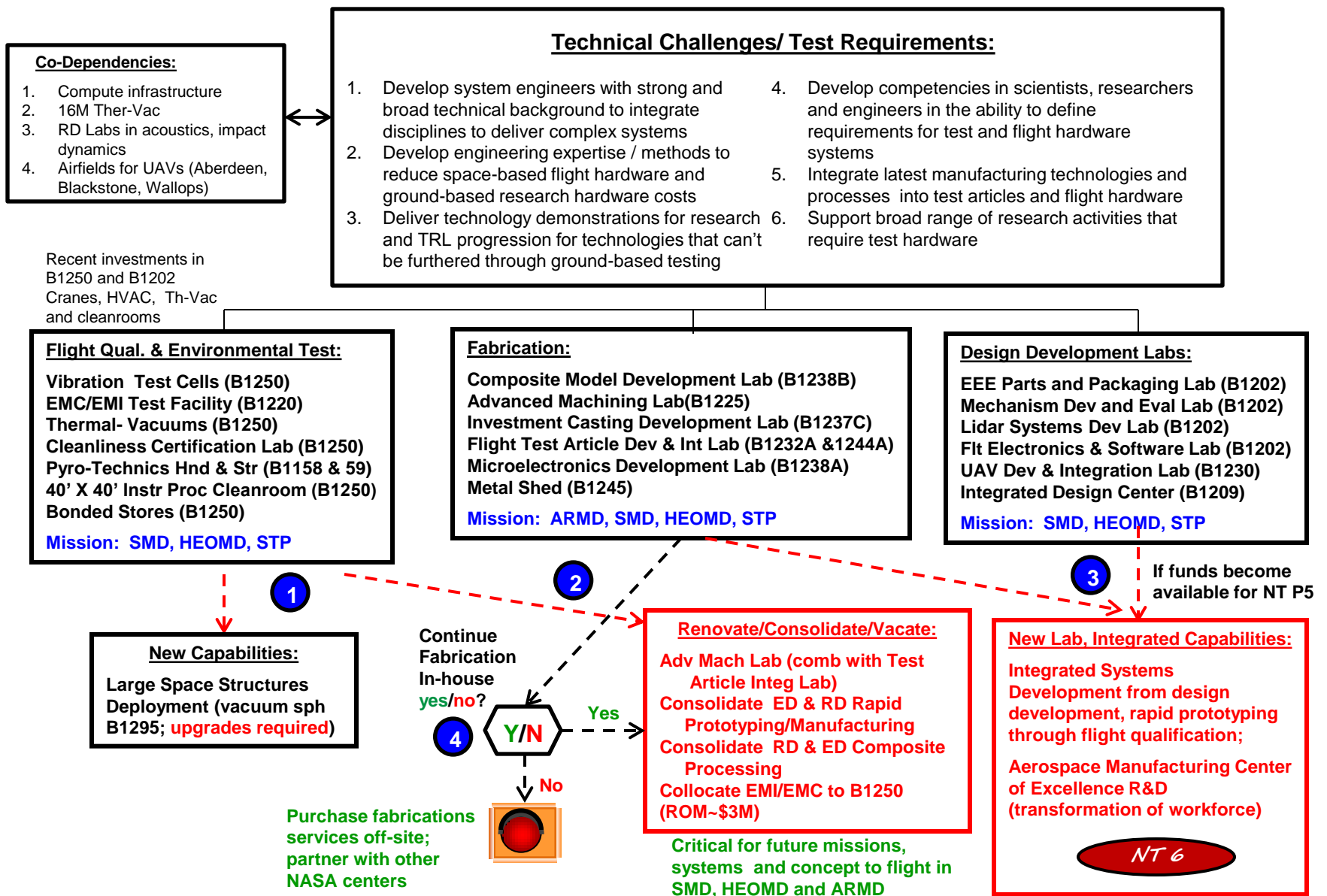
4.2 Conduct systems-level research on innovative and promising aeronautics concepts and technologies to demonstrate integrated capabilities and benefits in a relevant flight and/or ground environment.

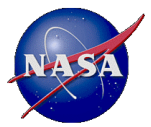
Integrated Systems Research Program

- Environmentally Responsible Aviation



7.0 Systems Development Facilities





7.0 Systems Development Facilities

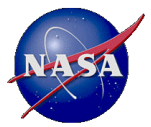
Key Decision Points (KDP):

7.1 Rehab large structures vacuum sphere (B1295) for new large space structures testing;

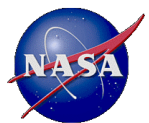
7.2 Consolidation Options: consolidate EMI/EMC Lab with the Environmental Test Lab in B1250 or other suitable location, if new high bay addition is necessary seek program funding (ROM~\$3M); develop new capability for IR Calibration (B1250) ROM~\$5M, see KDP 8.3 in Sensor Systems; optimize fabrication facilities; consolidate Center's essential composites processing capability into New Town #4, allowing B1267 to be demolished.

7.3 If New Town Phase 6 funds approved, consolidate multiple disciplines and associated fabrication labs and environmental test. Will allow B1209, remainder of B1250, B1232A, B1232B and B1225 to be vacated.

7.4 Continue fabrication services in-house, yes/no?



8.0 Sensor Systems Laboratories (Laser/Lidar and remote sensing)



8.0 Sensor Systems Laboratories



B1202

Remote Sensing & Laser/Lidar Labs



3 2

New Capabilities:

Laser/Lidar Test Range (1 Km)
Dual use T-Vac/IR Calibration

Technical Challenges:

1. **CLARREO** - Climate Absolute Radiance and Refractivity Observatory
2. **ALHAT** - Autonomous Landing and Hazard Avoidance Technology
3. **ASCENDS** - Active Sensing of CO₂ Emissions over Nights, Days, & Seasons
4. **GEO-Cape** - Geostationary Coastal and Air Pollution Events mission
5. **3-D WINDS** Dimensional Tropospheric Winds from Space-based Lidar
6. **Autonomous Rendezvous and Docking**
7. **CERES** - clouds and the Earth's Radiant Energy System
8. Wake vortex, clean air turbulence

Co-Dependencies: Systems Development, Science Laboratories, & Langley Aircraft

Remote Sensing (B1202):

Optical Receivers Development Lab
Optical Detectors Dev & Test Lab
Detector & Camera Electronics Dev Lab
Optical Metrology and Calibration Lab
Roof-Top Observatory Lab
Fabry-Perot Interferometry Lab
Camera Development and Test Lab

Mission: SMD, HEOMD, STP

Laser/Lidar Technology Development (B1202):

Laser/Lidar Electronics Lab
Laser Diode Characterization Lab
Laser Material Spectroscopy Lab
Laser Observatory Test Range
Laser Altimetry Lab
Diode Pumped Laser Lab
Coherent Lidar Receiver Lab
2 Micron Solid State Laser Lab
Lidar Systems Dev Lab (same as Systems Dev)
Photonics (HSRL B1299, Electromagnetics Lab)

Mission: SMD, HEOMD, STP

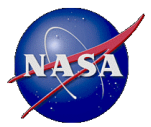
1

Critical for future missions, systems, & concept to flight in SMD and HEOMD

New Lab, Integrated Capabilities:

Integrate associated Laser/Lidar Labs,
Integrate associated Remote Sensing Labs
Integrate Nano Materials and Sensors Labs,
Consolidate Flight Avionics Labs and SD Labs

NT 3



8.0 Sensor Systems – Mission Relevance

Strategic Goal 1: Extend and sustain human activities across the solar system.

1.2 Develop competitive opportunities for the commercial community to provide best value products and services to low Earth orbit and beyond.

Commercial Spaceflight Programs

- Commercial Cargo
- Commercial Crew

1.3 Develop an integrated architecture and capabilities for safe crewed and cargo missions beyond low Earth orbit.

Exploration System Development Programs

- Multi-Purpose Crew Vehicle
- Orion Emergency Rescue Vehicle

Exploration Research and Development Programs

- Exploration Precursor Robotic Missions
- Flagship Technology Demonstrations
- Enabling Technology Dev & Demo
- Lunar Precursor Robotic Program

Strategic Goal 2: Expand scientific understanding of the Earth and the universe in which we live.

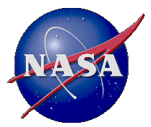
2.1 Advance Earth system science to meet the challenges of climate and environmental change.

Earth Science Programs

- Applied Sciences
- Earth Science Multi-Mission Operations
- Earth Science Research
- Earth Science Technology
- Earth System Science Pathfinder
- Earth Systematic Missions

Future Earth Science missions include:

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8.0 Sensor Systems – Mission Relevance

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- 3.3 Develop and demonstrate the critical technologies that will make NASA's exploration, science, and discovery missions more affordable and more capable.
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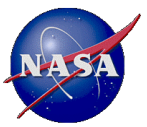
- **TA08. Science Instruments, Observatories, and Sensor Systems**
- **TA09. Entry, Descent, and Landing Systems**

Strategic Goal 4: Advance aeronautics research for societal benefit.

- 4.1 Develop innovative solutions and advanced technologies through a balanced research portfolio to improve current and future air transportation.

Aviation Safety Program

- **Atmospheric Environment Safety Technologies**



8.0 Sensor Systems Laboratories

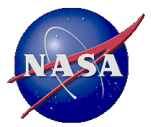
Key Decision Points (KDP):

- 8.1 In New Town Phase 3, integrate associated Laser/Lidar, Remote Sensing, and Flight Avionics Labs from B1202;
- 8.2 Develop a new Laser/Lidar Test Range (1Km), current ADLF site meets needs with building re-purposed (ROM~\$500K to repurpose B1258);
- 8.3: Develop a dual use Thermal-Vacuum and IR Sensor Calibration (co-locate with Environmental Test Lab in B1250 or alternate site) capability if program agrees to fund (ROM~\$5M);

Science Labs

Environmental
Test Lab





9.0 Entry, Descent, and Landing (cross-referenced to Aerothermodynamics, Mat. & Struc., & Sys. Dev.)



9.0 Entry, Descent, and Landing Facilities

(See cross-references to Aerodynamics, Aerothermodynamics, Hypersonics Airbreathing Propulsion, Materials and Structures, and Systems Development Facility Strategies)

Technical Challenges/ Test Requirements:

1. Aerodynamic characterization and stability of parachutes, inflatable aerodynamic decelerators, aeroshells, descent vehicles, landers, and their combinations
2. Supersonic aerodynamic characterization. Validation of RCS Interactions
3. TPS Materials Characterization, Unique CO₂ capability
4. Supersonic Retro-Propulsion (SRP) CFD Validation & configuration screening
5. Force/moment data for flight aero database or CFD validation
6. Hypersonic Gas Chemistry validation and CFD pressure model validation
7. High temperature testing of flexible / deployable TPS systems at flight heat rates and shear conditions.

Missions:

STP: HIAD, SIAD, Trim Tab

SMD/Planetary:

Lunar South Pole-Aitken Basin Sample Return

Venus In Situ Explorer

Saturn Probe

Comet Surface Sample Return

Trojan Asteroid Tour and Rendezvous

HEOMD: MPCV, and Commercial Cargo

Disciplinary Dependencies:

Aero-Sciences

Flight Dynamics

Structures and Materials

Systems Engineering

Thermal Protection

Systems Analysis

Coupled Loads Analysis

Aero-Propulsion

Guidance, Navigation and Control

Large-Scale, Precision Fabrication

Integration and Test

Compute Infrastructure

LaRC Wind Tunnels, Facilities, and Laboratories (cross-reference):

20" Mach 6 (see Aerothermodynamics)

31" Mach 10 (see Aerothermodynamics)

TDT (See Aerodynamics, unique planetary atmosphere simulation capability)

Unitary Plan Wind Tunnel (See Aerodynamics)

HyMETS (see Hypersonic Airbreathing Propulsion)

CF4 (See Aerothermodynamics)

8' High Temp (See Hypersonic Airbreathing Propulsion)

20' Ft Vertical Spin (See Aerodynamics)

LandIR (See Structures and Materials)

Other Facilities and Labs (not at LaRC):

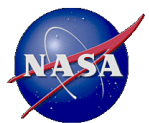
Arc Jets (ARC)

Ballistic Ranges (ARC)

Sounding Rocket and Balloon Programs (WFF)

Shock Tubes (HyPulse)

**New Lab and Integrated Capabilities
captured in above cross-references**



9.0 Entry, Descent, and Landing – Mission Relevance

Strategic Goal 1: Extend and sustain human activities across the solar system.

1.2 Develop competitive opportunities for the commercial community to provide best value products and services to low Earth orbit and beyond.

Commercial Spaceflight Programs

- Commercial Cargo
- Commercial Crew

1.3 Develop an integrated architecture and capabilities for safe crewed and cargo missions beyond low Earth orbit.

Exploration System Development Programs

- Multi-Purpose Crew Vehicle
- Orion Emergency Rescue Vehicle

Exploration Research and Development Programs

- Advanced Exploration Systems
- Exploration Precursor Robotic Missions
- Flagship Technology Demonstrations
- Enabling Technology Dev & Demo
- Lunar Precursor Robotic Program

Strategic Goal 2: Expand scientific understanding of the Earth and the universe in which we live.

2.2 Understand the Sun and its interactions with Earth and the solar system.

Heliophysics Programs

- Near Earth networks
- New Millennium

2.3 Ascertain the content, origin, and evolution of the solar system and the potential for life elsewhere.

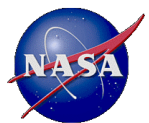
Planetary Science Programs

- Discovery
- Mars Exploration
- New Frontiers

2.4 Discover how the universe works, explore how it began and evolved, and search for Earth-like planets.

Astrophysics Programs

- Astrophysics Explorer
- Cosmic Origins Exoplanet Exploration



9.0 Entry, Descent, and Landing – Mission Relevance

Strategic Goal 3: Create the innovative new space technologies for our exploration, science, and economic future.

3.2 Infuse game-changing and crosscutting technologies throughout the Nation's space enterprise to transform the Nation's space mission capabilities.

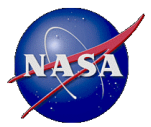
3.3 Develop and demonstrate the critical technologies that will make NASA's exploration, science, and discovery missions more affordable and more capable.

3.4 Facilitate the transfer of NASA technology and engage in partnerships with other government agencies, industry, and international entities to generate U.S. commercial activity and other public benefits.

NASA Space Technology Roadmaps:

TA09 Entry, Descent, and Landing Systems (possible future missions):

- Crewed orbital velocity return 2015
- Lunar sample return 2017/2022/2027
- Asteroid sample return 2017/2022/2027
- Venus lander 2017/2022/2027
- Mars sample return sample 2018
- ISS down-mass capability 2018
- Crewed high-vel Earth return 2020
- Mars sample return orbiter 2022
- Mars sample return surface 2024
- Crewed asteroid rendezvous 2025
- Mars network 2029
- Saturn probes 2032
- Titan aerial vehicle, landers 2032
- Crewed Mars Orbiter 2035
- Crewed Mars Surface 2041
- Icy Moon Lander 2042



10.0 Langley Aircraft



10.0 Langley Aircraft



Hawker Beech B200



Hawker Beech UC-12B



Cessna 206H



Cirrus SR22



Dassault HU-25C



Textron Bell UH-1H



Cessna Columbia
300 (LC-40), **storage**



Rockwell OV-10A
storage



Rockwell OV-10G
storage



Hangar and aircraft fuel storage
(multiple functions in B1244 unrelated to
aircraft operations)

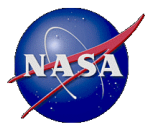


Flight Ops Support Ctr



Flight Sys Integration Lab

- Hawker Beech B200: modified with two nadir portals for remote sensing, isokinetic aerosol inlet and wing pylons
- Hawker Beech UC-12B: modified with same nadir portals as B200; production cargo door
- Cessna 206H: seating for subject pilot, safety pilot & researcher; equipped with LaRC GA Baseline Research System (GABRS)
- Cirrus SR22: composite structure; seating for subject pilot, safety pilot & researcher; equipped with GABRS & Surrogate UAS
- Dassault HU-25C: greater range, speed, and altitude than B200s
- Cessna Col 300 (LC-40): composite structure; original four seats; **flyable storage**
- Rockwell OV-10A: twin turboprop with tandem seating; aft cockpit can be reconfigurable for research; **flyable storage**
- Rockwell OV-10G: two aircraft, upgraded engines, propellers and avionics (potential for NAVAIR leasing); **flyable storage**
- Textron Bell UH-1H: only NASA research helicopter; low altitude; not currently instrumented; ready for prototype flash lidar for ALHAT
- Hangar & aircraft fuel storage: recently upgraded (upgraded roof, foam fire suppression sys.); used for DoD transient aircraft
- Flight Systems Integration Lab: in B1244; flight and research hardware/software integration; flight-to-simulator integration
- Flight Operations Support Center: provides real-time monitoring of flight ops via telemetry and video downlinks or relays to other sites



10.0 Langley Aircraft – Mission Relevance

Strategic Goal 2: Expand scientific understanding of the Earth and the universe in which we live.

2.1 Advance Earth system science to meet the challenges of climate and environmental change.

Earth Science Programs

- **Applied Sciences**
- **Earth Science Multi-Mission Operations**
- **Earth Science Research**
- **Earth Science Technology**
- **Earth System Science Pathfinder**
- **Earth Systematic Missions**

Future Earth Science missions include:

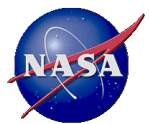
- **CLARREO** - Climate Absolute Radiance and Refractivity Observatory
- **ASCENDS** – Active Sensing of CO₂ Emissions over Nights, Days, & Seasons
- **GEO-Cape** - Geostationary Coastal and Air Pollution Events mission
- **3-D WINDS** Dimensional Tropospheric Winds from Space-based Lidar
- **CERES** – clouds and the Earth's Radiant Energy System
- **SAGE** – stratospheric aerosol and gas experiment

Strategic Goal 4: Advance aeronautics research for societal benefit.

4.2 Conduct systems-level research on innovative and promising aeronautics concepts and technologies to demonstrate integrated capabilities and benefits in a relevant flight and/or ground environment.

Integrated Systems Research Program

- **Unmanned Aircraft Systems in the National Airspace System**



10.0 Langley Aircraft

Co-Dependencies:

- 1.Science Directorate
- 2.Research Directorate
- 3.LAFB

Science Directorate Technical Challenges/Test Requirements:

1. Earth Radiation budget
2. Active Remote Sensing of aerosols
3. Active remote sensing of Atmospheric species (CO2, CO, O2, CH4, etc.)
4. Solar/Lunar Occultation
5. Air quality measurements
6. Mission validation (CALIPSO)
7. Instrument Validation (HSRL, etc.)
8. Atmospheric Modeling
9. Spectroscopy
10. Satellite Data analysis
11. Hyperspectral remote sensing
12. Far-IR for Planetary science
13. UAS in NAS operations development (ARD/RD)

Science Research Support Aircraft:

Hawker Beech B200 [2,3,5,6,7,11]
Hawker Beech UC-12B [2,3,5,6,7,11]
Cessna 206H [1,5,7,11]
Cirrus SR22 [13]
Dassault HU-25C [2,3,5,6,7,11]
Textron Bell UH-1H [7]
Hangar & Fuel Stor. [aircraft support]
Flt. Sys. Integ. Lab [1,2,3,5,6,7,11,13]
Flt. Ops. Support Ctr. [1,2,3,5,6,7,11,13]

Mission: SMD, HEOMD, ARMD

KDP 10.1 Continue to station Science Research Support Aircraft In-house at Langley. **yes/no?**

1



Yes

No

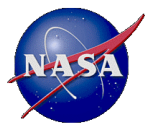


Capability sufficient for current & future planned work

Sustains essential aircraft operations capability

Space available in Hangar complex for consolidation

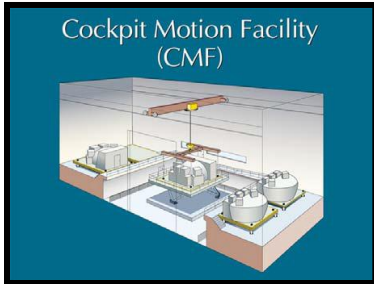
Station Langley aircraft at Wallops, PHF?, or Dryden; partner with Dryden



11.0 Flight Simulators



11.0 Flight Simulators



Cockpit Motion Facility (B1268)



Research Flight Deck (B1268)



Integration Flight Deck (B1268)



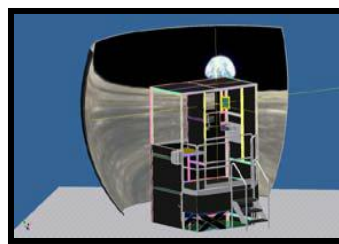
Generic Flight Deck (B1268)



Differential Maneuvering Simulator (B1268)



Development and Test Simulator (B1268)



Lunar Flight Deck (B1268)

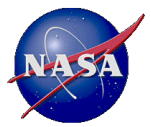


Visual Motion Simulator (B1268)



Research Systems Integration Lab (B1268)

- Cockpit Motion Facility: 3-axis motion; accommodates Research Flight Deck, Integration Flight Deck, and Generic Flight Deck
- Research Flight Deck: full mission functionality; operates in fixed or motion base; displays modeled after B787; GPS and ADS-B datalink
- Integration Flight Deck: full mission functionality; operates in fixed or motion base; replicates B757 flight deck
- Generic Flight Deck: glass generic cockpit; 2 crew & 3 observers; operates in fixed or motion base; interchangeable control inceptors
- Differential Maneuvering Sim: two identical 40' domes; 360-deg visual scene; vibration simulation; realistic cockpit environment
- Development and Test Sim: B777, MD-11, A-320 functionality; 2 crew & 3 observers; full mission functionality
- Lunar Flight Deck: pilot flies in standing position; reconfigurable simulator; visual system 135 deg horizontal by 67.5 deg vertical
- Visual Motion Sim: capability to be replaced by Cockpit Motion Facility; VMS will eventually be decommissioned
- Research Systems Integration Lab: human-in-the-loop simulates end-to-end mission; interfaced directly to simulators; com & nav capabilities



11.0 Flight Simulators – Mission Relevance

Strategic Goal 1: Extend and sustain human activities across the solar system.

1.2 Develop competitive opportunities for the commercial community to provide best value products and services to low Earth orbit and beyond.

Commercial Spaceflight Programs

- **Commercial Crew**

1.3 Develop an integrated architecture and capabilities for safe crewed and cargo missions beyond low Earth orbit.

Exploration System Development Programs

- **Multi-Purpose Crew Vehicle**
- **Orion Emergency Rescue Vehicle**

Strategic Goal 4: Advance aeronautics research for societal benefit.

4.1 Develop innovative solutions and advanced technologies through a balanced research portfolio to improve current and future air transportation.

Fundamental Aeronautics Program

- **Fixed Wing Project**
- **Rotary Wing Project**
- **High Speed Project**
- **Aeronautics Sciences Project**

Airspace Systems Program

- **NextGen Concepts and Technology Development**
- **NextGen Systems Analysis, Integration, and Transition**

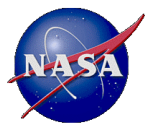
Aviation Safety Program

- **System-Wide Safety and Assurance Technologies**
- **Vehicle Systems Safety Technology**

4.2 Conduct systems-level research on innovative and promising aeronautics concepts and technologies to demonstrate integrated capabilities and benefits in a relevant flight and/or ground environment.

Integrated Systems Research Program

- **Unmanned Aircraft Systems in the National Airspace System**



11.0 Flight Simulators

Co-Dependencies:

1. Research Directorate

Technical Challenges/Test Requirements:

1. Air/Ground functional allocation
2. Airborne surveillance-based applications
3. Integration of UAS in the NAS
4. Eliminate need for pilot's natural vision outside cockpit
5. Visual display methods enabling massive probabilistic data tomes
6. Visual display methods for autonomous systems operations
7. Technologies and methods which retain the best of radio and data comm while eliminating worst
8. Culture-neutral, language neutral flight deck
9. Human/automation function allocation
10. Human systems integration for UAS in NAS
11. Human operator engagement and adaptive automation
12. Sustainability and validation of sim accuracy, sim/flight data interdependencies

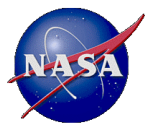
Research and Development:

Cockpit Motion Facility [1,4,6,7,8,9,11,12]
Research Flight Deck [1,4,6,7,8,9,11,12]
Integration Flight Deck [1,4,6,7,8,9,11,12]
Generic Flight Deck [1,4,6,7,8,9,11,12]
Differential Maneuvering Sim. [3,10,11]
Development & Test Sim. [1,4,6,7,8,9,11,12]
Lunar Flight Deck [9,11]
Research Sys. Integ. Lab [1,4,6,7,8,9,11,12]

Mission: ARMD, HEOMD

Simulators sufficient for current & future planned work

Sustains Essential Simulators and Laboratories



12.0 Flight Dynamics & Controls Labs

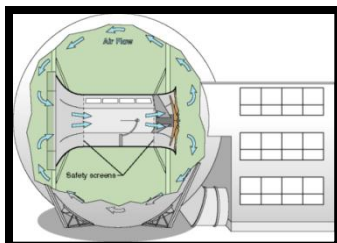


12.0 Flight Dynamics and Controls Laboratories

VST is ATP supported, located on East Side:
(capability addressed in aerodynamics)



Buildings 644, 645,
645A, and 646



12-Ft Low-Speed Tunnel



Vertical Spin Tunnel

Labs not supported by ATP, located on West Side



Exp Techniques Lab
(adjacent to 14x22, B1212)



Controls Research Lab
(B1232A)



Drop Shop (B1237C)

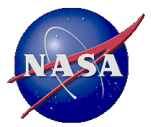
Technical Challenges:

1. System identification, self-directed flight test
2. Uncertainty modeling in nonlinear controls systems
3. Autonomy and unmanned air systems
4. Controls in complex nonlinear systems
5. Adaptive real-time guidance
6. Aerodynamic modeling for difficult flight regimes (nonlinear/unsteady flow, transonic)
7. Uncertainty requirements and quantification for flight mechanics simulations
8. Improved experimental and computational methods for modeling aeroelastic effects on flight mechanics predictions
9. Modeling and prediction of aerodynamic decelerator performance and dynamics
10. Operations, handling qualities, and dynamics/control of UAVs
11. Development of handling qualities criteria for piloted spacecraft and landers

Labs sufficient for current & future planned work

**Sustains Essential Flight Dynamics and
Controls Laboratories**

- 12-Ft Low-Speed Tunnel: housed in 60-ft sphere, max operation pressure is 7 psf (77 ft/sec at sea level), $Re \sim 492K$
- Vertical Spin Tunnel: 12-sided, 20 ft by 25 ft, velocity from 0 to 85 ft/sec, dynamically scaled free-flying models used to investigate large angle spinning, tumbling, out-of-control phenomena
- Experimental Techniques Lab: used for rig check-out, model build-up and teardown, evaluate new test techniques, adjacent to 14x22
- Controls Research Lab: general purpose lab areas comprising 6000 sq ft, open floor plan, standard electronic instrumentation, raised floor area, open mezzanine, and specialized computer equipment for DAC and real-time control
- Drop Shop: dedicated to supporting research flight of remotely piloted vehicles, build-up areas, workbenches, and overhead crane



12.0 Flight Dynamics & Controls – Mission Relevance

Strategic Goal 1: Extend and sustain human activities across the solar system.

1.2 Develop competitive opportunities for the commercial community to provide best value products and services to low Earth orbit and beyond.

Commercial Spaceflight Programs

- Commercial Cargo
- Commercial Crew

1.3 Develop an integrated architecture and capabilities for safe crewed and cargo missions beyond low Earth orbit.

Exploration System Development Programs

- Multi-Purpose Crew Vehicle
- Orion Emergency Rescue Vehicle
- Space Launch System

Exploration Research and Development Programs

- Exploration Precursor Robotic Missions
- Flagship Technology Demonstrations
- Enabling Technology Dev & Demo
- Lunar Precursor Robotic Program

Strategic Goal 3: Create the innovative new space technologies for our exploration, science, and economic future.

3.1 Sponsor early-stage innovation in space technologies in order to improve the future capabilities of NASA, other government agencies, and the aerospace industry.

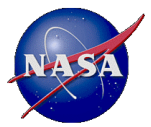
3.2 Infuse game-changing and crosscutting technologies throughout the Nation's space enterprise to transform the Nation's space mission capabilities.

3.3 Develop and demonstrate the critical technologies that will make NASA's exploration, science, and discovery missions more affordable and more capable.

3.4 Facilitate the transfer of NASA technology and engage in partnerships with other government agencies, industry, and international entities to generate U.S. commercial activity and other public benefits.

NASA Space Technology Roadmaps:

- TA01. Launch Propulsion Systems
- TA02. In-Space Propulsion Technologies
- TA09. Entry, Descent, and Landing Systems



12.0 Flight Dynamics & Controls – Mission Relevance

Strategic Goal 4: Advance aeronautics research for societal benefit.

4.1 Develop innovative solutions and advanced technologies through a balanced research portfolio to improve current and future air transportation.

Fundamental Aeronautics Program

- Fixed Wing Project
- Rotary Wing Project
- High Speed Project
- Aeronautics Sciences Project

Aviation Safety Program

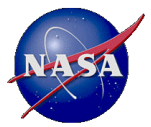
- System-Wide Safety and Assurance Technologies
- Vehicle Systems Safety Technology

Aeronautics Test Program

4.2 Conduct systems-level research on innovative and promising aeronautics concepts and technologies to demonstrate integrated capabilities and benefits in a relevant flight and/or ground environment.

Integrated Systems Research Program

- Environmentally Responsible Aviation
- Unmanned Aircraft Systems in the National Airspace System



13. Crew Systems & Aviation Operations Laboratories



13.0 Crew Systems & Aviation Operations Laboratories



Intermediate Design Eval and Sim (IDEAS) lab, B1268



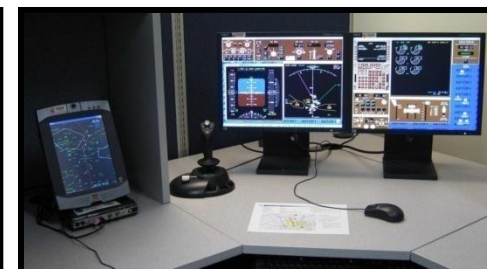
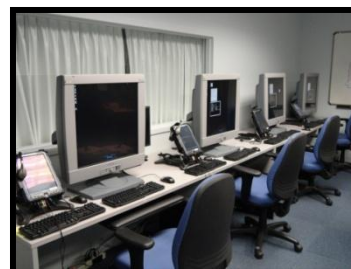
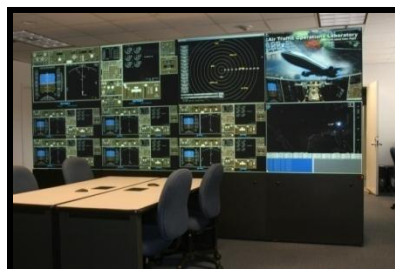
Operator Char & Perf Investigations Lab (OCAPI), B1268A



Visual Imaging Simulator of Trans Aircraft Sys (VISTA-III), B1268D

Technical Challenges / Test Requirements:

1. Air/Ground functional allocation
2. Airborne surveillance-based applications
3. Integration of UAS in the NAS
4. Eliminate need for pilot's natural vision outside cockpit
5. Visual display methods enabling massive probabilistic data tomes
6. Visual display methods for autonomous systems operations
7. Tech & methods which retain the best of radio & data com while eliminating worst
8. Culture-neutral, language neutral flight deck
9. Human/automation function allocation
10. Human systems integration for UAS in NAS
11. Human operator engagement and adaptive automation

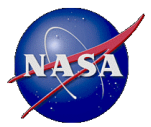


Air Traffic Operations Lab (ATOL), B1268

Labs sufficient for current & future planned work

Sustains essential Crew Systems & Aviation Operations Laboratories

- **IDEAS Lab:** low-to-medium fidelity simulation facility for quick turnaround experiments and prototype display development for human factors studies, human-in-the-loop evaluations, or single pilot simulation
- **ATOL Lab:** investigate multi-aircraft operations, ADS-B modeling of messages, prototype decision support tool for AFR ops
- **OCAPI Lab:** investigates functional status of human pilots for improved human/automation integration, pilot performance traits, use of attention distribution for display evaluation and use control of interfaces
- **VISTA-III:** visual flight simulator/workstation using COTS rear-screen projectors to replicate a pilot's visual surroundings



13.0 Crew Systems & Aviation Operations – Mission Relevance

Strategic Goal 1: Extend and sustain human activities across the solar system.

1.2 Develop competitive opportunities for the commercial community to provide best value products and services to low Earth orbit and beyond.

Commercial Spaceflight Programs

- **Commercial Crew**

1.3 Develop an integrated architecture and capabilities for safe crewed and cargo missions beyond low Earth orbit.

Exploration System Development Programs

- **Multi-Purpose Crew Vehicle**

Strategic Goal 4: Advance aeronautics research for societal benefit.

4.1 Develop innovative solutions and advanced technologies through a balanced research portfolio to improve current and future air transportation.

Airspace Systems Program

- **NextGen Concepts and Technology Development**
- **NextGen Systems Analysis, Integration, and Transition**

Aviation Safety Program

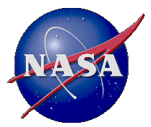
- **System-Wide Safety and Assurance Technologies**
- **Vehicle Systems Safety Technology**
- **Atmospheric Environment Safety Technologies**

Aeronautics Test Program

4.2 Conduct systems-level research on innovative and promising aeronautics concepts and technologies to demonstrate integrated capabilities and benefits in a relevant flight and/or ground environment.

Integrated Systems Research Program

- **Unmanned Aircraft Systems in the National Airspace System**



14.0 Science Laboratories and Atmospheric Science Data Center



14.0 Science Laboratories and Atmospheric Science Data Center



Capability to be consolidated into New Town #6

NT 6

Atmospheric Science Data Center (B1268C)

NT 4



Technical Challenges / Test Requirements:

- | | |
|---|---------------------------------------|
| 1. Earth Radiation budget | 7. Instrument Validation (HRSL, etc.) |
| 2. Active Remote Sensing of aerosols | 8. Atmospheric Modeling |
| 3. Active remote sensing of Atmospheric species (CO ₂ , CO, O ₂ , CH ₄ , etc.) | 9. Spectroscopy |
| 4. Solar/Lunar Occultation | 10. Satellite Data analysis |
| 5. Air quality measurements | 11. Hyperspectral remote sensing |
| 6. Mission validation (CALIPSO) | 12. Far-IR for Planetary science |

Science Laboratories (B1250)

Advanced Lidar Development Lab
Data Sys Int and Testing Lab
DLH/DACOM Laser Lab
Electronics Test Lab
Laser/ Lidar Lab
Lidar Development Lab
Molecular Spectroscopy Lab
Ozone Dial Test Lab
Sc Instrument Integration & Cal Lab

Mission: SMD

Labs sufficient for current & future planned work

Sustains essential Science laboratories



Co-Dependencies:

1. Research Aircraft
2. Compute Infra
3. Systems Development
4. ED Sensor Systems

• **Note:** SD operates field deployed instruments; ED develops fundamental measurement capability

Compute & Data Center Infrastructure

Atmospheric Sc Data Center - (B1268C)
Atmospheric Sc An Computer Rm (B1250)
CERES SCF Computer Room #1 (B1250)
CERES SCF Small Server Room #2 (B1250)
CERES SCF Staging Lab (B1250)
HALOE Server/Simulation Room (B1250)
INSTRUMENT SIMULATOR ROOM (B1250)
PROJECTS COMPUTER LAB (B1250)
SERVER LAB (B1250)

Mission: SMD

Compute Infrastructure sufficient for current & future planned work

Sustains essential Compute capability

Continue to consolidate compute in 1268 Compute Complex





14.0 Science Laboratories & Atmospheric Science Data Center-- -- Mission Relevance

Strategic Goal 2: Expand scientific understanding of the Earth and the universe in which we live.

2.1 Advance Earth system science to meet the challenges of climate and environmental change.

Earth Science Programs

- **Applied Sciences**
- **Earth Science Multi-Mission Operations**
- **Earth Science Research**
- **Earth Science Technology**
- **Earth System Science Pathfinder**
- **Earth Systematic Missions**

Future Earth Science missions include:

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- **ASCENDS** – Active Sensing of CO₂ Emissions over Nights, Days, & Seasons
- **GEO-Cape** - Geostationary Coastal and Air Pollution Events mission
- **3-D WINDS** Dimensional Tropospheric Winds from Space-based Lidar
- **CERES** – clouds and the Earth's Radiant Energy System
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Strategic Goal 3: Create the innovative new space technologies for our exploration, science, and economic future.

3.1 Sponsor early-stage innovation in space technologies in order to improve the future capabilities of NASA, other government agencies, and the aerospace industry.

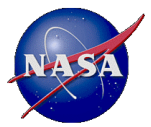
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3.3 Develop and demonstrate the critical technologies that will make NASA's exploration, science, and discovery missions more affordable and more capable.

3.4 Facilitate the transfer of NASA technology and engage in partnerships with other government agencies, industry, and international entities to generate U.S. commercial activity and other public benefits.

NASA Space Technology Roadmaps:

- **TA08. Science Instruments, Observatories, and Sensor Systems**



15. Measurement Sciences (flow physics, acoustics, and combustion)



15.0 Measurement Sciences (flow physics, acoustics, & combustion)



Acoustic Measurement Systems Lab (B1230)



AoA Development & Evaluation Lab (B1230)



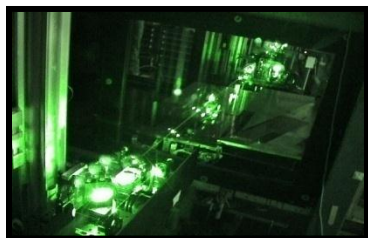
Harsh Environment Strain Gage Lab (B1230)



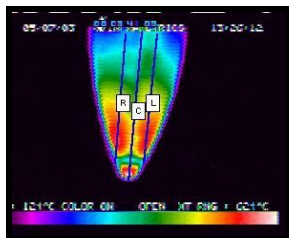
Adv Strain Measurement Lab (B1230)



Balance Calibration Lab (B1237B)



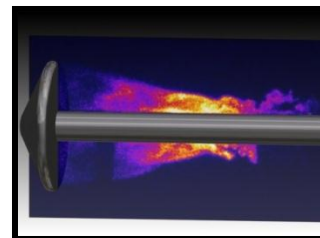
Flow Diagnostics Labs (B1200)



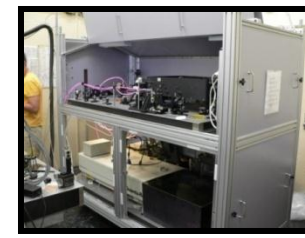
Chemical/Surface Diagnostics Labs (B1200)



Structural Diagnostics Labs (B1200)



Data Integr/Visualization Labs (B1200)



Nonintrusive Diagnostics Lab (CARS, B1221)

Acoustic Measurement Systems Lab: research and development of acoustic and infrasonic sensors.

AoA Development & Evaluation Lab: A. G. Davis Table for calibration of AoA sensors and integration of angle measurements; new systems for angle, rate, and acceleration measurements

Harsh Environment Strain Gage Lab: application of strain gages for hot structure testing (flame spray booth) and cryogenic applications

Advanced Strain Measurement Lab: development of new strain measurement sensors for structures, wind tunnel, and flight testing

Balance Calibration Lab: calibration of force and moment measurement systems for wind tunnel tests

Flow Diagnostics Labs: laser velocimetry, particle image velocimetry, Doppler global velocimetry, Coherent Anti-Raman Spectroscopy (CARS), laser induced fluorescence, laser induced thermal acoustics, Rayleigh Scattering

Chemical/Surface Diagnostics Labs: Pressure sensitive paint, temperature sensitive paint, IR thermography

Structural Diagnostics Labs: Photogrammetry / Videogrammetry, Project Moire interferometry

Data Integration / Visualization Labs: virtual diagnostic Interface (ViDi)



15. Measurement Sciences (flow physics, acoustics, & combustion)

-- Mission Relevance

Strategic Goal 4: Advance aeronautics research for societal benefit.

4.1 Develop innovative solutions and advanced technologies through a balanced research portfolio to improve current and future air transportation.

Fundamental Aeronautics Program

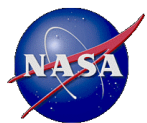
- Fixed Wing Project
- Rotary Wing Project
- High Speed Project
- Aeronautics Sciences Project

Aeronautics Test Program

4.2 Conduct systems-level research on innovative and promising aeronautics concepts and technologies to demonstrate integrated capabilities and benefits in a relevant flight and/or ground environment.

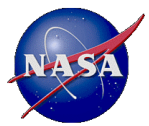
Integrated Systems Research Program

- Environmentally Responsible Aviation



15.0 Measurement Sciences (aerodynamics requirements)

Measurement Priorities		Comments	Technical Challenges Addressed											
Near Term (0-3 Years)														
1	Balance and angle of attack,6 DOF Force & Moments	Improvements in dynamic response and range of balances and AOA. AOA measurement needs to be at least one order of magnitude. Powered models will require improved flow-thru balances.	1,4-5,10,12											
2	Time-dependent velocity and pressure/density maps throughout flow fields of smooth-body separated flows	Currently requires seed particles in the flow to scatter light; getting particles into the core region is difficult. Planar and volumetric methods required	2-9, 14											
3	Far field sound	Phased array microphones	2, 3											
Mid Term (3-6 Years)														
1	Shear stress/skin friction	Re-establish LaRC capability in this area. Need the development of global and point sensors capable of high frequency (< 5 kHz). Other techniques also needed include global surface heat flux and pressure.	1-5, 8, 9, 12											
2	Improved surface pressure	Improve efficiency and accuracy global surface pressure. Higher frequency response of global surface pressure and low-cost robust sensors.	1, 2, 4, 6-11											
3	Volumetric flow characterization	Tomographic flow measurement technique	2-9, 14											
4	Improved shape sensing	Increase acquisition rates, analysis rates, and efficiency of existing systems to determine actual surface shapes	2-10, 12-13											
Long Term (6-10 Years)														
1	Improved global flow field measurements, inflow condition, time correlations of velocities, separation bubbles, wakes and jets	High frequency multipoint velocimetry techniques	8, 9, 14											
2	BL and shear layer velocities and Reynolds stresses	Required for turbulence modeling and fundamental flow physics. Difficult to make close to the surface on a wind tunnel model; embedded sensor systems	5-6, 8-9, 14											
3	Molecular-Based, Non-Intrusive High-Frequency, Near-Surface Velocity in BL	Required for turbulence modeling and simulation. Seedless techniques.	2-9,14											
Challenge #	1	2	3	4	5	6	7	8	9	10	11	12	13	14
Aerodynamic Challenge	Prop-Airframe Integration /Acoustics	Jet Interaction	Noise Source Identification	CFD Code Development	CFD Data Verification	Flow Control	Fluid-Structure Interaction	Fundamental Flow Physics (Turbulence, Transition, Separated Flows)	Highly Unsteady Flows, Including Rotor Aero	Performance (6 DOF F, M, P, T)	Blunt Bodies (for EDL)	Flight Dynamics (Stability and Control)	Exploratory Research; Novel Configurations	Turbulence Modeling



15.0 Measurement Sciences (acoustics requirements)

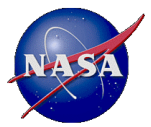
Measurement Priorities		Comments	Technical Challenges Addressed
Near Term (0-3 Years)			
1	Single & phased array microphone measurements; characterization of atmospheric conditions during flight testing	Efficient high-count array hardware and software Remote sensing of all weather parameters	1
Mid Term (3-6 Years)			
1	Planar high-frequency fluctuating multi-component velocity field; velocity-velocity & pressure-velocity correlations; Planar high-frequency pressure & temperature fields; Model shape; Farfield noise measurements (all simultaneous)	Enhanced seeding systems and/or planar molecular techniques. New technology for pressure/ temperature/velocity correlations.	4-7,11-14
2	Single microphone measurements over several square miles; characterization of atmospheric conditions during flight testing	Command/control of mics over large area. Intelligent sensor systems. Remote sensing of all weather parameters	1,3
3	Global structural response; Acoustic intensity	Currently has scanning vibrometry capability - need multi-point / multi-plane capability in this area. Multi-point /planar/curved surface vibrometry; Microphone measurements	9,10
Long Term (6-10 Years)			
1	Global high-frequency fluctuating multi-component velocity field; velocity-velocity & pressure-velocity correlations; Global pressure & temperature fields; Model shape; Farfield noise measurements (all simultaneous)	Enhanced seeding systems and/or planar molecular techniques. New technology for pressure/ temperature/velocity correlations with simultaneous acoustic measurements.	4-7,11-14
2	Single mics; simultaneous surface radiation, structural response, and global external fluctuating surface pressure	External measurements in flight are the most pressing need.	2
3	Global pressure and structural strain and velocity in a harsh environment (2000 deg F and 172 dB)	High temperature and noise transducers for pressure.	8

1	Flyover Noise Assessment of Aircraft and Operations (EER/IER/MAF)	4	Acoustic and Flow Field Characterization of Propulsion Concepts (LSAWT/SAJF)	7	Development of Advanced Acoustic Measurement Methods (QFF)	10	Vibroacoustic Characterization (SALT)	13	Characterization of Integrated Propulsion/Airframe in Realistic Environment (14x22)
2	Cabin Noise Assessment of Aircraft and Materials (SALT/Flight)	5	Performance of Nozzles for Uniform and Mixed Flow (LSAWT/SAJF)	8	High Cycle Fatigue of Structures for Thermal/Acoustic Loads (TAFA)	11	Development of Acoustic Liners for Noise Reduction (LTF)	14	Validation of Models and CFD/CAA Codes (14x22, LTF, LSAWT, SAJF, TAFA)
3	Evaluation/Modeling of Human Response to Sonic Boom (IER/MAF/EER)	6	Small-scale Testing for Concept Development and Validation (QFF)	9	Transmission Loss Characteristics and Validation of New Concepts (SALT)	12	Characterization of Liner Skin Friction Drag and Acoustic Performance (LTF)		

Measurement Priorities		Comments	Technical Challenges Addressed
Near Term (0-3 Years)		Implementation of High-Payoff, Existing Capabilities	
1	Turn-Key flow visualization and quantification (seeded/planar)	Locally-seeded technique that is revealing critical Information about flow field structure, velocity, density, and temperature.	2, 3, 6, 7, 8
2	Intrusive High-Frequency Surface and Flow Field Pressure and Temperature	Very difficult, but within-reach capability to provide hypersonic measurements on and near surface and in flow field. Can be disruptive of small-model flow field..	3, 6, 8, 9, 11
Mid Term (3-6 Years)		Development of Horizon Capabilities	
1	Model shape and surface deformation during testing	Can provide surface displacements, stress, and strain. Potential application for mapping global surface heating and pressure to actual model 3D geometry..	1-5, 8, 9, 12
2	Flow visualization and quantification (seedless/planar)	Currently possible for characterization tunnel flow quality, and with continued development will provide non-intrusive measurements in model flow field.	1, 2, 4, 6-11
3	High precision single point multi-parameter flow measurements	Provide pressure, velocity, speed of sound, temperature. Applicable to stagnation point, powered-model inlet and exit regions, and shock/shock interactions.	1, 4, 6, 8, 9- 11
Long Term (6-10 Years)		Research of New Capabilities	
1	Non-equilibrium Temperature, Density, Species	Laboratory and special-niche techniques applicable to most aerothermodynamic technical challenges.	1, 2, 4, 5-11
2	Molecular-Based, Non-Intrusive, Near-Surface and Flow Field Velocity and pressure	Required for undisturbed measurements in highly-nonlinear hypersonic interaction regions.	1-11
3	Molecular-Based, Non-Intrusive High-Frequency, Near-Surface Velocity in BL	Required for turbulence modeling and simulation.	3, 10, 11

Challenge #	1	2	3	4	5	6	7	8	9	10	11	12
Aerothermodynamic Challenge	Aeroelastic interactions for large, inflatable deployable aeroshells	RCS & thruster performance & interactions for maneuvering and control	Boundary-layer transition effects	Stage, payload, shroud interactions	Aerothermo of complex topological features	Retro-propulsion & stagnation-point injection for deceleration, maneuvering, cooling	Unsteady wake-flow physics and associated wake and shear layer impingement	Shock-shock Interactions with inlets, wings, control surfaces, towed ballutes	Multi-Gas, Planetary Aerodynamics	High-enthalpy chemical and vibrational non-equilibrium effects during atmospheric entry	High Re Number Turbulent Heating Physics	Aerodynamic Controls Performance

Measurement Priorities				Comments				Technical Challenges Addressed			
Near Term (0-3 Years)											
1	Flowfield imaging and quantification of minor species, temperature and fuel concentration (seeded)			Provide sub-mm spatial resolution images of flow. Use natural seeding of NO or OH or locally-seeded fuel jet to visualize combustion, flow field structure, measure velocity, mole fraction and temperature.				1,2,7,9,10			
2	Single-point, multi-parameter simultaneous measurement of temperature and concentration (seedless)			Spatially (~2 mm) resolved single-point measurement of temperature and major species mole fractions (N2, O2, H2, C2H4, CO, CO2) in supersonic combustion flows, including ducted flows with windows.				2,9,10			
3	Path averaged, line of sight, high speed measurement; also tomographic measurement (seedless)			Path-averaged temperature, O2, H2O measurement at inlet and exhaust as well as combustion control; Tomography can provide spatially resolved data even in complex flow environments (eg. 8'HTT)				1,2,6			
4	Single point simultanous velocity, sound speed and pressure (seedless)			Spatially resolved (~10 mm) measure of pressure, velocity, speed of sound (convert to temperature if composition is known).				10			
5	Planar or volumetric imaging of flow velocity field, multi component (seeded)			Provide 2 or 3 components of velocity in a plane (existing capability) or can be extended to volume. Some freestreams can be seeded using silane, fuels seeded with Al2O3.				2,7,9,10			
Mid Term (3-6 Years)											
1	Multi-point, multi-parameter, simultaneous measurement of temperature, concentration and velocity (high spatial resoluion, seedless)			High spatial resoulution (~0.2 mm) measure of temperature, density, velocity, major species (N2, O2, H2, CH4, C2H4, CO, CO2, H2O) in combustion flows. Can add techniques for minor species too.				9,10			
Long Term (6-10 Years)											
1	Method for unstart control			Need to detect precursor to combustion-induced unstart				6			
2	Molecular-based, high-frequency measurements in ducts, including combustion			Required for combustion/turbulence modeling and simulation. Need to measure temperature, velocity, density, species. Measurements needed at up to MHz rates. Technique unknown.				1,2,7,9,10			
Challenge #	1	2	3	4	5	6	7	8	9	10a	10b
Hypersonic Air Breathing Propulsion Challenge	Integrated engine free jet testing	Scramjet flowpath configuration development	Propulsion database generation	Inlet performance and operability limits	Flight hardware ground test verification	Propulsion controls system development	Fuel injection and mixing	Isolator/ combustor performance and ops limits	Fuels research/ testing	CFD model validation: mixing and combustion	CFD model validation: inlet and isolator



15.0 Measurement Sciences (flow physics, acoustics, & combustion)

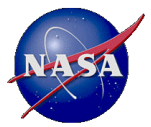
Key Decision Points (KDP):

15.1 Relocate the Advanced Sensing and Optical Measurements Laboratories in B1200 to B1230 after the current rehab is completed, then demolish B1200.

15.2 Establish an investment strategy to enable deployment of highest priority methods that are **Near-Term** (research development essentially complete) into the large scale tunnels with enhancements to enable rapid reduction of data to measurements of test attributes of interest. For deployment to multiple tunnels, some duplication of equipment and cross-training of facility personnel is advisable. For **Near-term methods (1-3 years, depending on method)**, ROM estimated cost for one technique \$500K/year for equipment procurement, 1.5 FTE/year and 2.0 WYE/year.

15.3 Advocate for research funding to fully develop highest priority methods that are still under laboratory development. For **Mid-term methods (development time ~3-6 years)**, ROM estimated cost for one technique \$50K/year for equipment procurement, 2.0 FTE/year and 1.0 WYE/year. After achieving TRL 7, consider field deployment (KDP #2). For **Long-Term (research and development time ~6-10 years)** methods, ROM estimated cost for one technique 1.5FTE/year and \$150K/year equipment procurement and student or post-doc costs. After achieving TRL 5, establish requirements for field deployment (KDP 15.2).



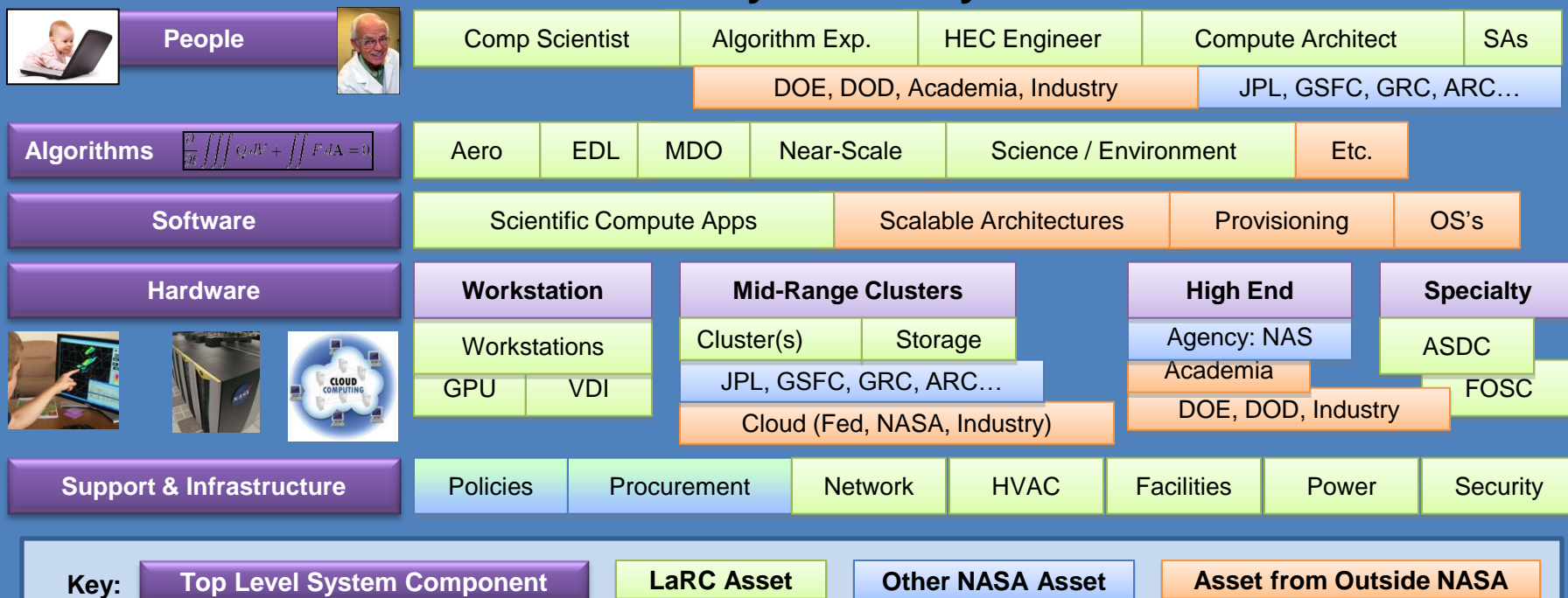


16. Compute Infrastructure (Computer hardware, networks, software & codes)



16.0 Compute Infrastructure (computer hardware, networks, software & codes)

A Balanced System of Systems



Current State:

- Existing center compute assets are fragmented among directorates; large amounts of hardware are end-of-life or antiquated; codes are incompatible with emerging architectures; expertise base is aging.
- Capabilities include CFD, EDL, System Design, Analysis, Environmental Modeling, etc.

Envisioned Future:

- Advanced compute can enable completely new missions and lines of work; e.g. "Digital Twin," multidisciplinary optimization, high-resolution concept-to-flight system analysis.
- A revitalized LaRC Compute System of Systems would provide advanced support to all center missions and provide agility to rapidly take on emerging, changing missions.
- Core LaRC capabilities would leverage assets from across NASA, government, academia, and industry.
- Revitalization will require commitment, cooperation, collaboration, consolidation, and investment.



16.0 Compute Infrastructure (computer hardware, networks, software & codes)

Compute Assets		Aerodynamics	Acoustics	Aerothermodynamics	Hypersonic Airbreathing Propulsion	Materials and Structures	Electromagnetics and Flight Systems Laboratories	Systems Development (Fabrication, Engineering and Environmental Testing)	Sensor Systems (Laser/Lidar and remote sensing)	Entry, Descent, and Landing	Langley Aircraft	Flight Simulators	Flight Dynamics and Controls Laboratory	Crew Systems and Aviation Operations Laboratories	Science Laboratories and Atmospheric Science Data Center	Measurement Sciences
High-End	NAS	✓	✓	✓	✓	✓		✓		✓			✓		✓	
	DOE	✓														
Mid-Range	Branch Cluster	✓	✓	✓	✓	✓		✓		✓		✓			✓	✓
	K Cluster	✓	✓	✓	✓	✓										
Low-End	Server	✓	✓	✓	✓	✓		✓		✓		✓		✓	✓	✓
	Workstation	✓	✓	✓	✓	✓	✓	✓	✓	✓	✓	✓		✓	✓	✓
	Desktop	✓	✓	✓	✓	✓	✓	✓	✓	✓	✓	✓	✓	✓	✓	✓
Speciality	ATOL										✓			✓		
	ASDC						✓		✓						✓	✓
	FOSC							✓	✓	✓				✓		
	Personnel	✓			✓			✓	✓	✓						
Potential Capabilities	Center Cluster	↑	↑	↑	→	↑		↑		↑	→	↑			→	↑
	Cloud	→	→	→	→	→		→		→					→	
	FMSC								↑	↑	↑			↑	↑	↑
	Algorithm Dev	↑	↑	↑	↑	↑		↑		↑		↑	↑		↑	↑
Directorate Applicability	ED	✓	✓	✓		✓	✓	✓	✓	✓		✓				✓
	RD	✓	✓	✓	✓	✓	✓	✓	✓	✓	✓	✓		✓		✓
	SACD	✓	✓	✓	✓	✓			✓	✓		✓			✓	✓
	ESOD	✓		✓	✓	✓	✓		✓			✓				
	FPD	✓		✓	✓	✓	✓	✓	✓	✓						
	SD					✓	✓	✓							✓	✓

ASDC	Atmospheric Sciences Data
ATOL	Air Traffic Operations Lab
EDL	Entry, Descent, and Landing
FOSC	Flight Operations Support
FMSC	Flight Mission Support Center

↑	Can make use of asset if available
→	Potential use if asset available

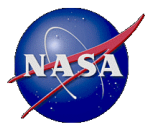


16.0 Compute Infrastructure (computer hardware, networks, software & codes)

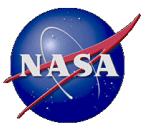
Key Decision Points (KDP):

16.1: Should LaRC embrace cutting-edge compute capability as a key differentiator, helping to lead NASA into the virtual age? Compute can be a key differentiator for LaRC, especially in the area of algorithm development. If yes, strategic decisions must be made regarding the following factors that will be keys to success:

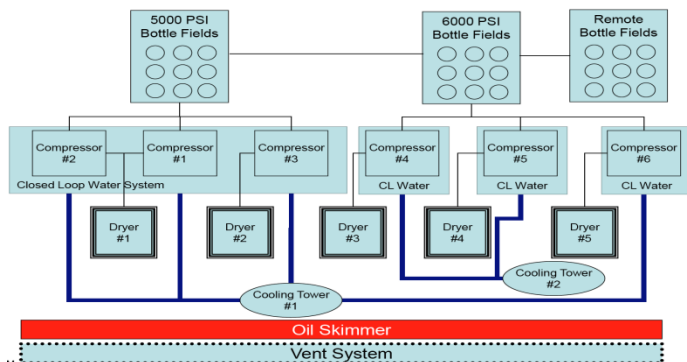
1. Address workforce requirements to assure that the Center has the skill mix and critical mass of subject matter experts to institutionalize the KDP.
2. Include space for a cutting edge compute facilities in New Town 4 (or rehab to B1194)?
Compute space in New Town allows green, efficient computing; retrofitting and maintaining existing facilities is costly. Possibility of containerized compute for augmentation.
3. Consolidate common compute assets, while allowing selected unique capabilities?
Consolidating enables economies of scale and efficiencies. Manage well to ensure everyone gets what they need.



17.0 Compressor Station



17.0 Compressor Station Facility



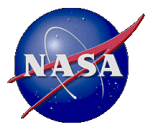
Technical Challenges:

1. Maintain Compressor Station to a safe and operable steady-state that enables continued operations in light of reduced budgets for maintenance and repair.
2. Provide approximately 800-900 klbs of air daily to support research testing.
3. Increase MTBF (Mean Time Between Failures) to industry standard for new equipment of 2400 hours (current MTBF = 134 hours).

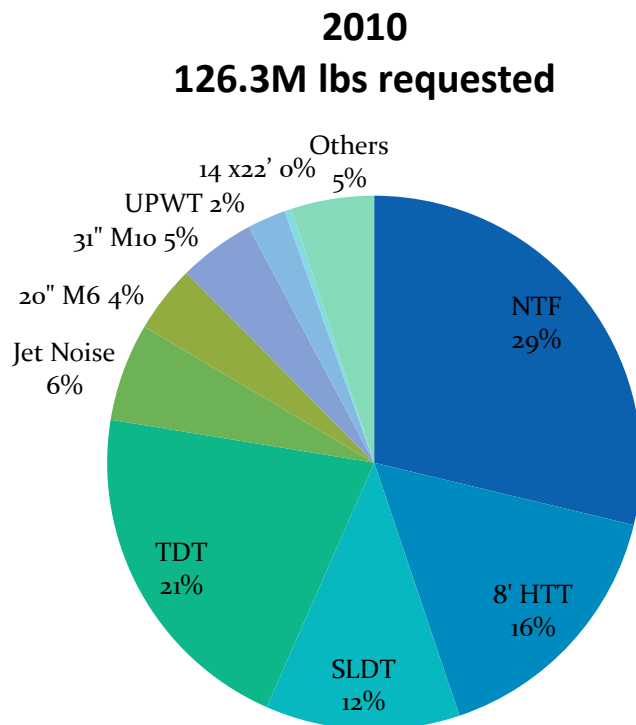
Co-Dependent Disciplines:

1. Aerodynamics
2. Aerothermodynamics
3. Hypersonics
4. Entry, Descent and Landing

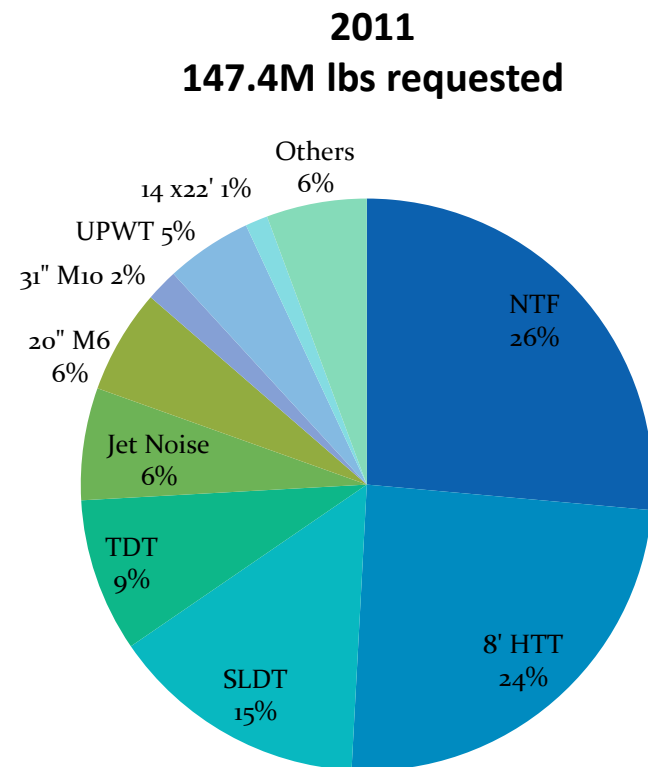
- The compressor station is the “heart” of the wind tunnel testing capability at LaRC providing compressed air to more than a dozen wind tunnels, including those located on the East side (NTF, 8’HTT, SLDT, TDT, Jet Noise, 20”M6, 31”M10, UPWT, 14x22, etc).
- The station consists of 5 active (and one mothballed) compressors installed from 1952-1975: three large (8#/sec @ 6ksig) and two small (2.5#/sec @ 5ksig), five dryers, 2 cooling towers, bottle fields for storage, support equipment, and miles of piping for distribution.
- Mean Time Between Failures (MTBF) in 2010 was 134 hours, well short of a new compressor operation with its design life (2400-2600 hours).
- All compressors are well in excess of their design life and require significant continued investment to maintain safe and operational.



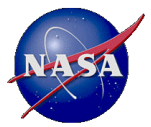
17.0 Compressor Station Facility



72.0M lbs delivered



94.4M lbs delivered



17.0 Compressor Station Facility

Key Decision Points (KDP):

Note: The center continues to operate with a “run-to-failure” maintenance policy, and neither preventative nor conditioned-based maintenance is being performed on a regular basis, except on certain safety-critical components. These practices, if continued into the future, will inevitably result in a degradation of system reliability over time.

17.1 Immediately embark on repair by replacement effort, replacing the existing 3 small compressors (#1,2, and 3) with one new large compressor (8 lbs/sec, 6000 psi) reciprocating compressor and dryer within 3 years (\$15M).

17.2 Systematically assess remaining compressors over the course of the next 15-18 years using a phased approach, the decision on each phase dictated by system capacity reassessment and budget.

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